Emergency Services Control Model

for

Next Generation Networks

Ruiz Planella, Joaquim
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ETSETB, UPC

Supervisor: Fabricio Gouveia (FOKUS Fraunhofer Institut Berlin)
Co-supervisor: Prof. Dr. Thomas Magedanz (FOKUS Fraunhofer Institut Berlin)
Technische Universität Berlin

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Abstract

Emergency services are among the most fundamental and critical services to be offered by telecommunications networks. As countless new applications arise in heterogeneous network environments, there is an urge of adaption in Next Generation Networks to serve all kind of emergency situations with the appropriated Quality of Service. In earlier times, call signaling on a circuit-switched network proved sufficient to provide preferential treatment and ensure suitable Quality of Service. However, since Next Generation Networks are based on packet-switched technology – which is fundamentally different from circuit-switched technology – there is a need to consider the technical issues and potential solutions that could prove themselves useful in the improvement and realization of emergency telecommunications capabilities in Next Generation Networks.

The Internet Engineering Task Force (IETF) and the International Telecommunication Union (ITU) – among other international organizations – have focused their efforts in the development of standards and recommendations for effective emergency telecommunications in Next Generation Networks. Nevertheless, there exists a need for a better delimitation and definition of certain aspects in the different possible final solutions.

This thesis describes the design of a scalable model for emergency in Next Generation Networks, which follows the general lines established by the IETF and the ITU-T recommendations, for enabling operators to offer working and efficient communications under emergency situations.

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Chapter 1

Introduction

1.1 Motivation

The IP Multimedia Subsystem (IMS) is a key component of third generation (3G) networks. The IMS consists of a control layer that enables the seamless provision of IP multimedia services to end users. Among all these services, emergency services are one of the fundamental services that need to be supported by the IMS. Emergency services enable the public to summon help in case of emergencies, and enable the authorities as well to respond quickly in order to minimize loss of life and property.

Functioning and effective telecommunications are fundamental during and after disasters, be they natural or man-made, and it is specially in these particular situations that communications might congest at a very high rate. Therefore, emergency sessions need to be prioritized over non-emergency sessions to ensure fast dissemination of information and coordination. For the more, it becomes clear that the control of Quality of Service in the on-going non-emergency sessions or even the acceptance of new non-emergency sessions is a key feature for the success of emergency services in critical situations.

For all these reasons we propose a scalable model for telecommunications operators for the support of emergency services, which through specific thresholds and local policies will enhance the performance of Next Generation Networks even under exceptional circumstances.

1.2 Scope

The scope of this thesis lies on the definition of the thresholds through a proposed scenario, design of local policies, scalability of the model, related work and validation of the scalable model for Emergency Services.

Departing from the requirements of the model we will work on the defined scenario to define the basic thresholds and the bandwidth distribution that, later on the thesis, will be the basis to develop the scalability of the model. Within the study of the scenario we will define a call acceptance algorithm (to implement through specifically designed local policies), as well as establish the different systems, techniques and architectures in order to achieve the goals that will be defined in Chapter 3.

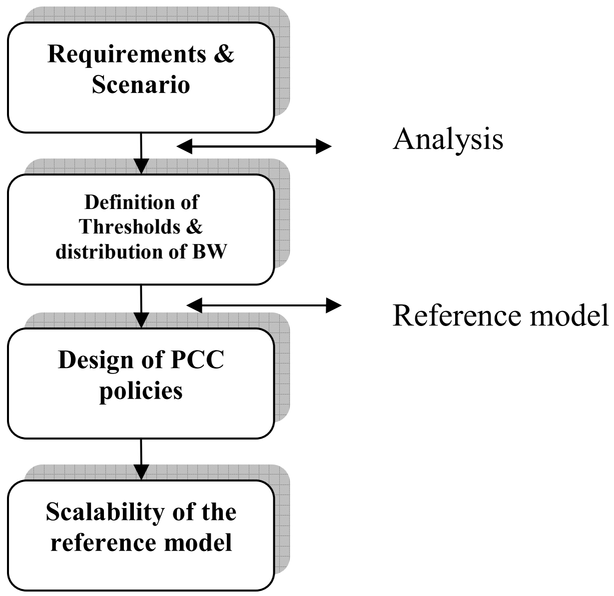

Figure 1.1: Structure of the thesis

The main results of the analysis of the scenario will be translated into policy rules, in order to allow the implementation of the proposed scalable model in current and future Next Generation Networks.

1.3 Outline

Chapter 2 describes related work and proposed standards for Emergency Telecommunications Services, as well as a short description of the different technologies that we will be working with.

Chapter 3 establishes the objectives of the thesis and the requirements for the development of the scalable model for Emergency Services.

Chapter 4 presents and analyses the scenario, defines the different thresholds, the call acceptance algorithm, the scalable model and the model for the local policies.

Chapter 5 describes the validation of the model through the recommendations of the ITU-T for emergency telecommunications and the validation of the scalable model with different short scenarios.

Chapter 2

Related Work and Standardization

2.1 Next Generation Networks (NGNs)

The NGN concept takes into consideration new realities in telecommunication industry characterized by factors such as the need to converge and optimise the operating networks and the extraordinary expansion of digital traffic. The NGN is a broad term used to refer certain key architectural evolutions in telecommunications and access networks that are currently in development and will be deployed within the near future. The main idea is that one network transports all information and services by encapsulating them into packets, being that the reason why NGNs are commonly built around the Internet Protocol (IP).

Summarizing, the phrase NGN refers to the current move from circuit switched to packet based networks. This will mean reduced costs for service providers who will, in turn, be able to offer a richer variety of services.

According to the Study Group 13 of the International Telecommunication Union (ITU-T), which works on standards for NGNs, the definition of an NGN [19] is the following:

"A Next Generation Network (NGN) is a packet-based network able to provide services including Telecommunication Services and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent from underlying transport-related technologies. It offers unrestricted access by users to different service providers. It supports generalized mobility which will allow consistent and ubiquitous provision of services to users."

2.1.1 Fundamental aspects of the NGNs

The NGNs are characterized by the fundamental aspects presented below:

- Packet-based transfer.
- Separation of control functions among bearer capabilities, call/session and application/service.
- Decoupling of service provision from network and provision of open interfaces.
- Support for a wide range of services, applications and mechanisms based on service building blocks (including real time/ streaming/ non-real time services and multi-media).
- Broadband capabilities with end-to-end QoS and transparency.
- Interworking with legacy networks via open interfaces.

- Generalized mobility.
- Unrestricted access by users to different service providers.
- A variety of identification schemes which can be resolved to IP addresses for the purpose of routing in IP networks.
- Unified service characteristics for the same service as perceived by the user.
- Converged services between Fixed/Mobile.
- Independence of service-related functions from underlying transport technologies.
- Compliant with all Regulatory requirements, for example concerning emergency communications and security/privacy, etc.

2.1.2 Overview of the NGN architecture

Along with a new architecture, the Next Generation Network will bring an additional level of complexity beyond that of existing networks. In particular, support for multiple access technologies and mobility results in the need to support a wide variety of network configurations. In an NGN there is a well-defined separation between the transport layer and the service layer, implying that whenever a provider desires to enable a new service, they can do it directly at the service layer without considering the transport layer

Figure 2.1 shows an overview of the NGN functional architecture, where the separation between the service stratum and transport stratum is clearly presented.

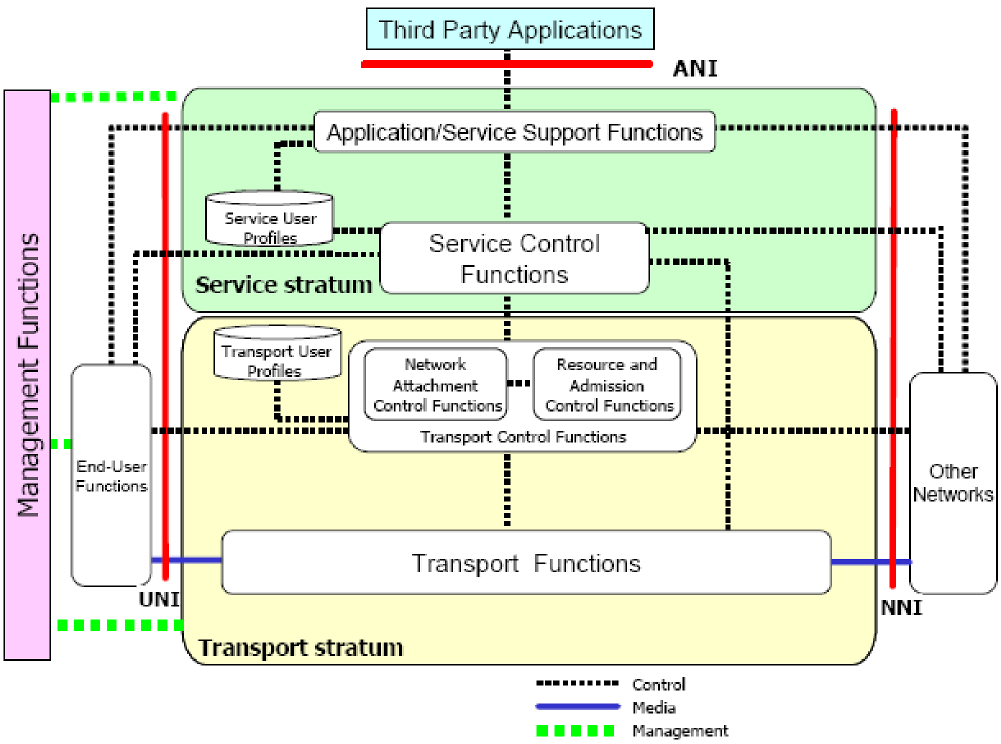

Figure 2.1: NGN architecture. Source [19]

The delivery of services/applications to the end-user is provided by utilizing the Application/Service Support functions and Service control functions. The NGN supports a reference point to the "Third-Party Applications" functional group called Application-to-Network Interface (ANI), enabling application of NGN capabilities to create and provision enhanced services for NGN users.

2.1.2.1 The transport stratum

NGN service stratum: that part of the NGN which provides the user functions that transfer service-related data and the functions that control and manage service resources and network services to enable user services and applications.

The Transport stratum provides IP connectivity services to NGN users under the control of Transport control functions, including the Network Attachment Control Functions (NACF) and Resource and Admission Control Functions (RACF).

The transport control functions RACF and NACF are explained in more detail in the following sections.

2.1.2.1.1 Resource and Admission Control Functions (RACF)

In the NGN Architecture, the Resource and Admission Control Functions (RACF) provide QoS control (including resource reservation, admission control and gate control), NAPT and/or FW traversal control Functions over access and core transport networks. Admission control involves checking authorisation based on user profiles, SLAs, operator specific policy rules, service priority, and resource availability within access and core transport.

Within the NGN architecture, the RACF act as the arbitrator for resource negotiation and allocation between Service Control Functions and Transport Functions. The RACF interacts with Service Control Functions and Transport Functions for Session-based applications (e.g. SIP call) and non-session based applications (e.g. Video Streaming) that require the control of NGN transport resource, including QoS control and NAPT/FW control and NAT Traversal. The RACF interacts with Transport Functions for the purpose of controlling one or more the following functions in the transport layer: Packet filtering; Traffic classification, marking, policing, and priority handling; Bandwidth reservation and allocation; Network address and port translation; Firewall. The RACF interact with Network Attachment Control Functions (NACF, including network access registration, authentication and authorization, parameters configuration) for checking user profiles and SLAs held by them.

2.1.2.1.2 Network Attachment Control Functions (NACF)

The NACF provides registration at the access level and initialization of end-user functions for accessing NGN services. These functions provide network-level identification/authentication, manage the IP address space of the access network, and authenticate access sessions. They also announce the contact point of NGN

Service/Application support functions to the end user. The NACF provides the following functionalities:

- Dynamic provision of IP addresses and other user equipment configuration parameters.
- Authentication at the IP layer (and possibly other layers).
- Authorization of network access, based on user profiles.
- Access network configuration, based on user profiles.
- Location management at the IP layer.

2.1.2.2 The service stratum

NGN transport stratum: that part of the NGN which provides the user functions that transfer data and the functions that control and manage transport resources to carry such data between terminating entities. The service control functions and the application/service support function are explained in further detail in the following sections.

2.1.2.2.1 Service control functions

The Service control functions include both session and non-session control, registration, and authentication and authorization functions at the service level. They can also include functions for controlling media resources, i.e., specialized resources and gateways at the service-signalling level.

2.1.2.2.2 Application/Service support functions

The Application/Service support functions include functions such as the gateway, registration, authentication and authorization functions at the application level. These functions are available to the “Third-Party Applications” and “End-User” functional groups. The Application/Service support functions work in conjunction with the Service control functions to provide end-users and third party application providers with the value added services they request.

Through the UNI (see Figure 2.1), the Application/Service support functions provide a reference point to the end-user functions (e.g., in the case of third-party call control for Click to Call service). The Third-party applications’ interactions with the Application/Service support functions are handled through the ANI reference point (See Figure 2.1).

2.2 IP Multimedia Subsystem (IMS)

IMS is a global, access independent and standard-based IP connectivity and service control architecture that enables various types of multimedia services to end-users using common internet-based protocols. Indeed, the IMS was originally designed by the 3rd Generation Partnership Project (3GPP) (with the collaboration of the European Telecommunications Standards Institute (ETSI)) and is a standardization of the NGNs architecture described in the previous section.

The advantages of the access independence and the standard-based IP connectivity permit the IMS to be as flexible, mobile and scalable as the Internet, as well as allowing an impressive range of multimedia services to be offered by Public Land Mobile Network (PLMN) operators to their subscribers. Examples of these services can be (among others) business applications, conferencing, on-line gaming, telecommunications services as Voice over IP (VoIP), presence, messaging and group management.

2.2.1 IMS architecture

This section introduces the basic IMS architecture [7] concepts. The basic requirements which guide the way in which the IMS architecture has been created and how it should be developed in the future have been documented by the 3GPP; the most significant ones are presented below:

- IP multimedia sessions: IMS users are able to mix and match a variety of IP-based services in any way they choose during a single communication session. Users can integrate voice, video and text, content sharing and presence as part of their communication and can add or drop services whenever they decide to do it.
- IP connectivity: A device has to have IP connectivity to access it.
- Ensuring QoS for IP multimedia services: This feature is one of the most remarkable among all introduced by the IMS. The underlying access and transport networks together with the IMS provide end-to-end QoS. Via the IMS, the User Equipment (UE) negotiates its capabilities and expresses its QoS requirements during a Session Initiation Protocol (SIP) session setup or modification procedure. The UE can negotiate, among many others, parameters such as:
    - Media type, direction of traffic
    - Media type bit rate, packet size, packet transport frequency
    - Bandwidth adaption
- IP policy control for ensuring correct usage of media resources: Implying the capability to authorize and control the usage of bearer traffic intended for IMS media, based on signalling parameters at the IMS session.
- Secure communication: The IMS has its own authentication and authorization mechanisms between the UE and the IMS network in addition to access network procedures (e.g., GPRS network).
- Charging arrangements: The IMS allows different charging models to be used, including the capability to charge just the calling party or to charge both the calling and the called parties based on resources in the transport level.

- Support of roaming: This feature makes it possible to use services even when the user is not geographically located in the service area of the home network.
- Interworking with other networks: The IMS supports communication with Public Switched Telephone Network (PSTN), Integrated Service Digital Network (ISDN), mobile and Internet users.
- Service development: The IMS architecture includes a service framework that provides the necessary capabilities to support speech, video, multimedia, messaging, file sharing, data transfer, gaming and basic supplementary services within the IMS.
- Layered design: The transport and bearer services are separated from the IMS signalling network and section management services. The layered approach increases the importance of the application layer as services are designed to work independent of the access network.
- Access independence.

2.2.1.1 Access network

Users can connect through their UE registering directly on an IMS network (it can be the home network or a visited network, roaming). The specific requirements for the UE are supporting IP protocol and running SIP user agents. The IMS supports fixed, mobile and wireless access networks.

2.2.1.2 Core network

The IP Multimedia Core Network subsystem comprises all CN elements for provision of multimedia services. This includes the collection of signaling and bearer related network elements. IP multimedia services are based on an IETF defined session control capability which, along with multimedia bearers, utilizes the IP-Connectivity Access Network (IP-CAN). The reference architecture of the IP Multimedia Core Network Subsystem is shown in Figure 2.2 and the most significant elements are described in the following subsections.

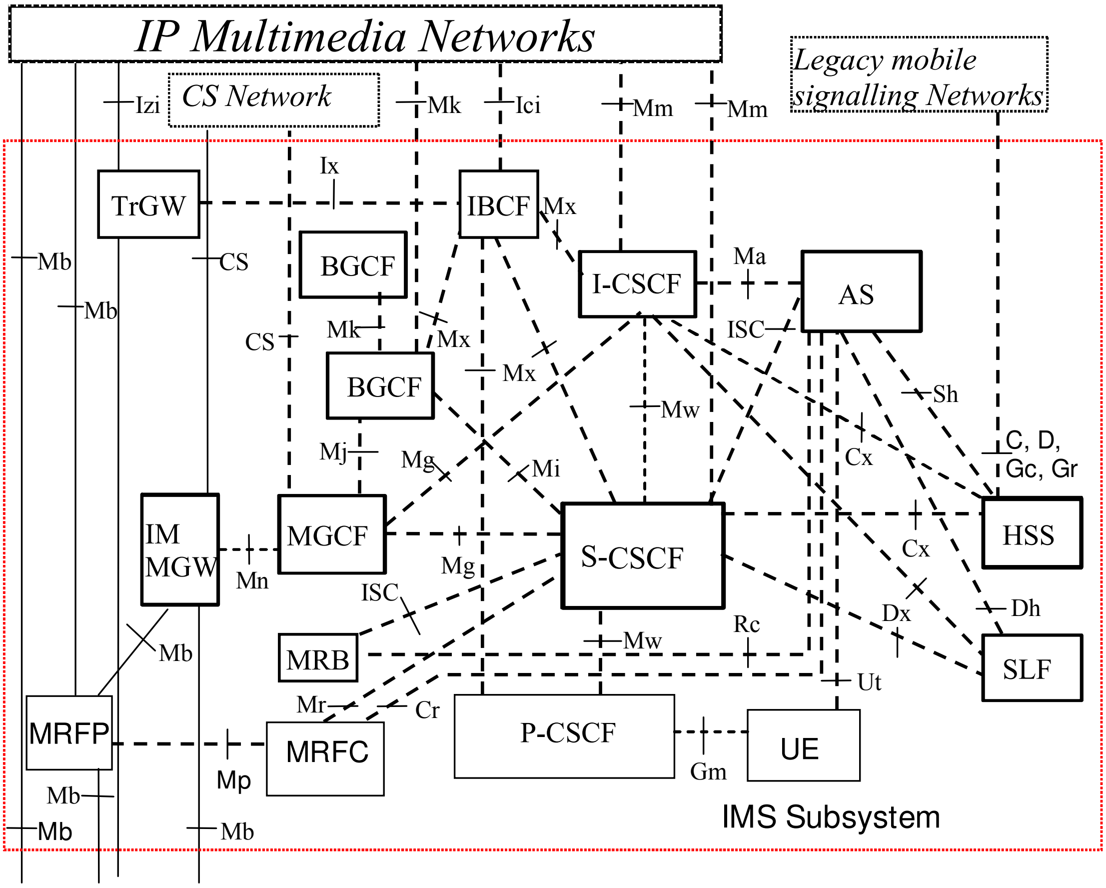

Figure 2.2: Reference Architecture of the IP Multimedia Core Network Subsystem. Source [7]

2.2.1.2.1 Databases: Home Subscriber Server (HSS) and Subscription Locator Function (SLF)

The HSS is the main data storage for all subscriber and service-related data of the IMS. The main data stored in the HSS include user identities (private or public), registration information, access parameters (used to set up sessions) and service-triggering information (enables SIP service execution).

The HSS provides user-specific requirements for Serving-Call Session Control Function (S-CSCF) capabilities. This information is used by the Interrogating- CSCF (I-CSCF) to select the most suitable S-CSCF for a user.

The HSS also contains the subset of Home Location Register and Authentication Center (HLR/AUC) functionality required by the Packet-Switched (PS) and the Circuit-Switched (CS) domains. There may be more than one HSS in a home network, depending on the number of mobile subscribers, the capacity of the equipment and the organization of the network.

The SLF is used as a resolution mechanism that enables the I-CSCF, the S-CSCF and the Application Server (AS) to fins the address of the HSS that holds the subscriber data for a given user identity when multiple and separately addressable HSSs have been deployed by the network operator.

2.2.1.2.2 Call Session Control Functions

There are three CSCFs: Proxy-CSCF (P-CSCF), S-CSCF and I-CSCF. The tasks of each CSCF are described in this section. The main point that all the CSCFs have in common is that they all take part in the registration and session establishment and form the SIP routing machinery of the IMS.

- P-CSCF: It is the first contact point for users within the IMS. Therefore, all signaling traffic from the UE will be sent to the P-CSCF. Among the tasks of the P-CSCF there are the SIP compression, IP-Secure (IPSec) security association and interaction with the Policy Decision Function (PDF).
- I-CSCF: It is a contact point within an operator's network for all connections destined to a subscriber of that network operator. The tasks assigned to the I-CSCF are: to obtain the name of the next hop; to assign an S-CSCF based on received capabilities from the HSS; to route incoming requests further to an assigned S-CSCF or the AS; and to provide Topology Hiding Inter-network Gateway (THIG) functionality.
- S-CSCF: It is a cornerstone of the IMS as it is responsible for handling registration processes, making routing decisions and maintaining session states, and storing the service profiles (a collection of user-specific information that is permanently stored in the HSS).

2.2.1.2.3 Services: Application Server and Media Servers

The ASs are not pure IMS entities (they are rather functions on top of IMS) that host and execute services. The main functions of the AS are:

- The possibility to process and impact an incoming SIP session received from the IMS.
- The capability to originate SIP requests.
- The capability to send accounting information to the charging functions.

The services offered are not limited to SIP-based services since an operator is able to offer access to services based on Customized Applications for Mobile network Enhanced Logic (CAMEL) Service Environment (CSE) and Open Service Architecture (OSA) for its IMS subscribers. Therefore, AS is the term generically used to capture the behavior of the SIP AS, OSA Service Capability Service (SCS) and CAMEL IP Multimedia Service Switching Function (IM-SSF).

The media servers are the Media Resource Function Controller (MRFC) and the Media Resource Function Processor (MRFP), which together provide mechanisms for bearer-related services such as conferencing, announcements or bearer trans-coding in the IMS architecture. The MRFC is tasked to handle SIP communication to and from the S-CSCF and to control the MRFP. The MRFP provides user-plane resources that are requested and instructed by the MRFC.

2.2.1.2.4 Interworking functions

The Breakout Gateway Control Function (BGCF) is used for communicating with the CS network (e.g., the PSTN). If the breakout happens in the same network, the BGCF selects a Media Gateway Control Function (MGCF) –which performs call control protocol conversion between SIP and ISDN User Part (ISUP) or Bearer Independent Call Control (BICC)– to handle the session further.

The MGCF controls the IMS Media Gateway (IMS-MGW), which provides the user-plane link between CS CN networks and the IMS.

2.2.2 The Policy and Charging Control (PCC) architecture

In this section we briefly explain the characteristics of the different functional elements of the PCC architecture [5]. In Figure 2.3 the overall PCC logical architecture is presented.

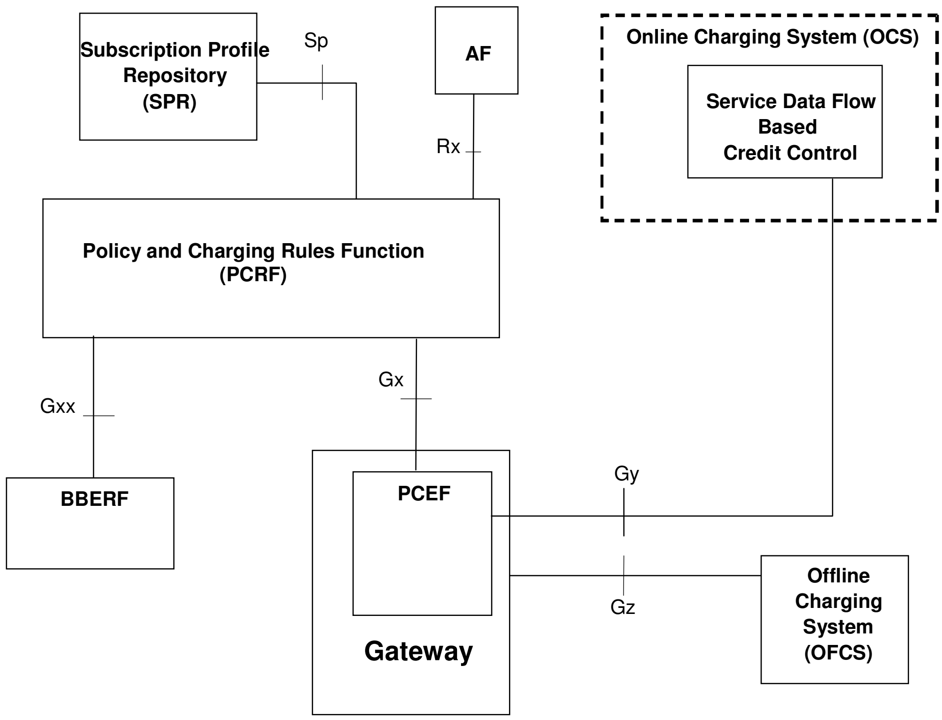

Figure 2.3: PCC architecture. Source [1]

The Rx reference point is used for transporting session-related information from the P-CSCF to the Policy Control and Charging Rules Function (PCRF) in order to reserve resources in the connectivity layer needed for session establishment.

The PCRF is a functional element that encompasses policy control decision and flow based charging control functionalities. It provides network control regarding the service data flow detection; gating, QoS and flow based charging towards the Policy and Charging Enforcement Function (PCEF). The PCRF receives session and media related information from the Application Function (AF) and informs the AF of traffic plane events.

The PCEF is the functional element that encompasses policy enforcement and flow based charging functionalities. This functional entity is located at the Gateway. It provides control over the user plane traffic handling at the Gateway and its QoS, and provides service data flow detection and counting as well as online and offline charging interactions.

The AF is an element offering applications that require dynamic policy and charging control over the IP-CAN user plane behavior. The AF shall communicate with the PCRF to transfer dynamic session information, required for PCRF decisions as well as to receive IP-CAN specific information and notifications about IP-CAN bearer level events. An AF can communicate with multiple PCRFs.

The Subscription Profile Repository (SPR) logical entity contains all subscriber related information needed for subscription-based policies and IP-CAN bearer level PCC rules by the PCRF

The Bearer Binding and Event Reporting Function (BBERF) includes the functionalities of bearer binding, uplink bearer binding verification, event reporting to the PCRF and sending/receiving IP-CAN-specific parameters to/from the PCRF.

2.3 IMS emergency sessions

This section describes the changes introduced by the 3GPP in the IMS architecture in order to implement control over emergency services in the IP Multimedia Core Network Subsystem [4], basically new functions are added and particularly the Emergency-CSCF (E-CSCF), which is further explained within the next sub-sections. Currently Fraunhofer Institute for Open Communication Systems (FOKUS) [15] is working on the development of the necessary extensions under the PEACE project [32], which are not yet implemented.

2.3.1 Principles and requirements

In addition to the architectural principles that apply to the IMS Core Network, the following additional principles [4] apply to IMS emergency sessions (we present the most significant ones):

- The IMS network should be able to discriminate between emergency sessions and other sessions. Special treatment should be provided for emergency sessions.
- The P-CSCF is the IMS network entity responsible to detect the request for emergency sessions and forward the request to the E-CSCF.
- The E-CSCF is the IMS network entity that should be able to retrieve geographical location information from the Location Retrieval Function (LRF)

in the case that the geographical location information is not available but required.

- The E-CSCF is the IMS network entity responsible to route the request to an emergency centre/Public Safety Answering Point (PSAP) or BGCF based on location information and additionally other information such as type of emergency service in the request.
- When a UE performs an emergency registration, barring and roaming restrictions are ignored.
- The P-CSCF serving the emergency call is the IMS network entity responsible for retrieving the location identifier from the IP-CAN.
- If the UE has location information available, then it may include the location information in the request to establish an emergency session.
- The E-CSCF should be able to query the LRF to validate the location information if provided initially by the UE.
- The E-CSCF is responsible for routing the emergency request to the PSAP/Emergency Centre that corresponds to the type of emergency service requested and the current location of the UE or to a default PSAP/Emergency Centre. It is as well responsible for forwarding the SIP request containing the UE's location information to the PSAP/Emergency Centre.
- The IP-CAN may support emergency services free of charge.

Regarding the additional requirements established by the 3GPP for the IMS Emergency Service architecture, the most significant are presented below:

- Emergency services are independent from the IP-CAN regarding the detection and routing of emergency sessions.
- The system should prioritize emergency sessions over non-emergency sessions.
- Establishment of IMS emergency sessions should be possible for users with a barred public user identity.
- Emergency Service is not a subscription service. Therefore, whenever the UE has roamed out of its home network, emergency services shall not be provided by the home network, but in the visited network if it supports emergency sessions.
- Emergency centers and PSAPs might be connected to the PSTN, CS domain, PS domain or any other packet network.
- The IMS Core Network should be able to transport information on the location of the subscriber.
- The network should be able to retrieve the caller's location.
- The network might provide a capability to enable a UE to obtain local emergency numbers.

2.3.2 Reference architecture for IMS ES

In this section we present the architecture model and describe the new features and functionalities of the elements presented in section 2.1.2, as well as the new CSCF for Emergency Services (the E-CSCF) and the LRF. The reference architecture is shown in Figure 2.4.

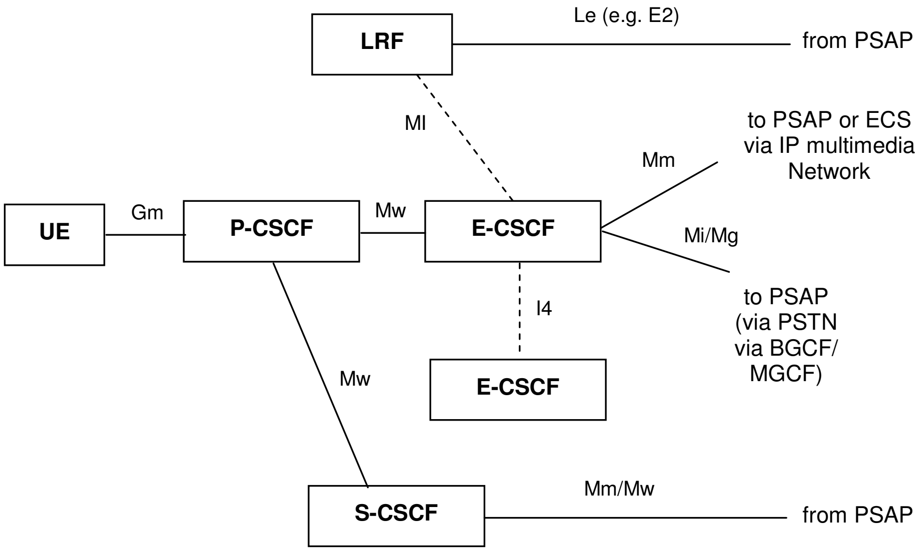

Figure 2.4: Reference architecture including the E-CSCF. Source [4]

In the presented architecture the UE should be able to detect an emergency session establishment request, as well as to initiate an IMS emergency registration request. For the more, the UE should include identity information for the IP-CAN when available and an emergency service indication in the emergency session request. When the UE initiates the emergency session establishment request, the following information is supplied in the request message: Emergency session indication; UE’s location information when available; and, optionally, type of emergency service.

Regarding the P-CSCF, it must be able to detect an emergency session establishment request, prioritize emergency sessions and reject or allow unmarked/anonymous emergency requests. The P-CSCF is also responsible for selecting an E-CSCF in the same network to handle the emergency session request and may query IP-CAN for location information.

The E-CSCF receives the emergency session establishment requests from the P-CSCF. Whenever location information is not included, the E-CSCF may request the LRF to retrieve it; when included, the E-CSCF may request the LRF to validate it. The E-CSCF must be able to determine (or query the LRF for it) the routing information or PSAP destination. The E-CSCF might, if needed, route the emergency IMS call to an Emergency Call Server (ECS) for further processing, based on local policy.

The retrieval of the location information of the UE initiating an IMS emergency session is responsibility of the LRF. The information that the LRF provides the E-CSCF includes routing information and other emergency services parameters.

Additional functionalities of the MGCF might be determining if an incoming call from the PSTN is for the purpose of PSAP call-back (based on local policy), and including a PSAP call-back indication in the SIP session establishment request.

2.3.3 Example of an establishment of an IMS emergency session

In Figure 2.5 we can appreciate the high level procedures for the establishment of an IMS emergency session when the UE is capable of detecting an emergency session. The steps followed during the procedure are explained below.

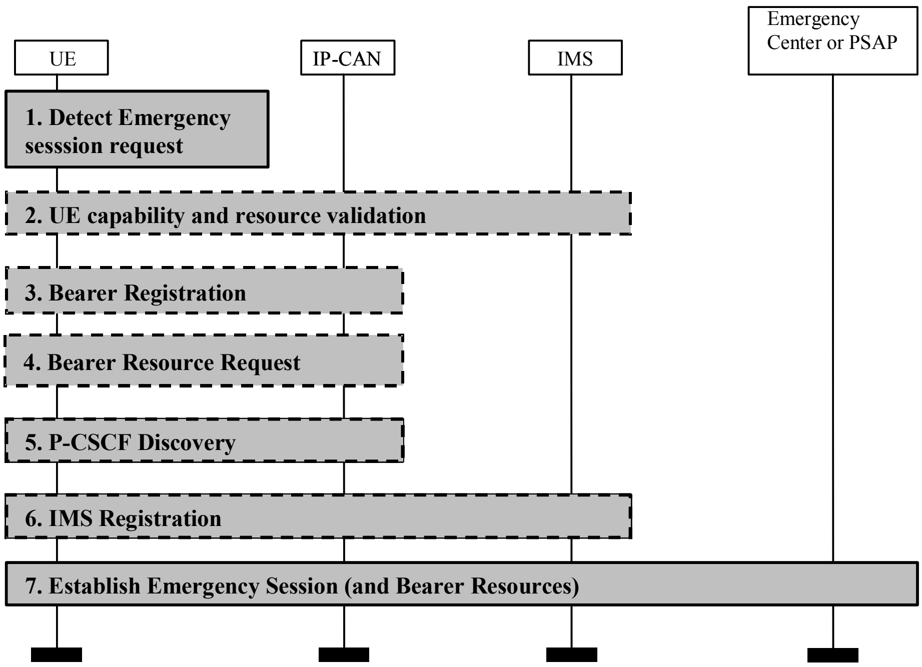

Figure 2.5: Emergency session establishment. Source [4]

1. The UE detects the request for the establishment of an emergency session.
2. If the UE has insufficient resources or capabilities to establish an emergency call, it should terminate the ongoing communication and release reserved bearer resources.
3. If the bearer registration is required and has not been performed, the UE shall perform bearer registration to the IP-CAN.
4. If the bearer resources for the transport of the IMS related signaling are required to be reserved in the IP-CAN, the UE shall reserve the resources in the IP-CAN. The IP-CAN may support a UE indication that this request is for an emergency service.
5. The UE performs a P-CSCF discovery procedure, where it discovers a P-CSCF in the local network suitable for use in emergency sessions.
6. If the UE has sufficient credentials to authenticate with the IMS network, it shall initiate an IMS emergency registration by providing the IP address obtained at step 3 or step 4 to the P-CSCF selected at step 5. The IMS registration request

shall include an emergency indication. If the UE does not have sufficient credentials, it shall not initiate an IMS emergency registration request, but instead establish an emergency session towards the P-CSCF.

7. The UE shall initiate the IMS emergency session establishment using the IMS session establishment procedures containing an emergency session indication and any registered Public User Identifier.

2.4 Session Initiation Protocol and the priority field

SIP is an application layer protocol – based on the Hypertext Transfer Protocol (HTTP) and the Simple Mail Transfer Protocol (SMTP) – that is used for establishing, modifying and terminating multimedia sessions in an IP network. It is part of the multimedia architecture whose protocols are continuously being standardized by the IETF. Its applications include – but are not limited to – voice, video, gaming, messaging, call control and presence. SIP can as well invite participants to existing sessions, such as multicast conferences.

Among the private header extensions for SIP there are some specific for the 3GPP, which are briefly described in the following list:

- P-Charging-Vector: It transports the IMS Charging ID and correlated access network related charging information between IMS network entities.
- P-Charging-Function-Address: It transports the addresses of the charging functions between IMS network entities of the user's home network.
- P-Visited-Network-ID: It transports the identification string of the visited network to the home network of the user during registration, allowing the home network to discover details about the roaming agreements between the two networks.
- P-Access-Network-Info: It transports information about the access network technology and the user's location from the visited network to the home network.
- P-Called-Party-ID: It is included in an initial request registrar of the terminating user. The registrar re-writes the request-Uniform Resource Identifier (URI) with the registered contact address of the terminating user. The URI originally indicated in the request-URI is saved to the P-Called-Party-ID header and sent along with the request.
- P-Associated-URI: It is included in the OK (200) response of a register request. It includes additional URIs that are associated with the user.

An interesting SIP header is the Priority header field [33], which indicates the urgency of the request as perceived by the client. This header describes the priority that the SIP request should have to the receiving human or its agent. For example, it may be factored into decisions about call routing and acceptance. For these decisions, a message containing no Priority header field should be treated as if it specified a Priority of "normal". The header field can have the values "non-urgent", "normal", "urgent", and "emergency", but additional values can be defined.

2.5 Differentiated Services

In the core of high-capacity networks service differentiation might be helpful to support applications' utilization of the network. The Differentiated Services (DiffServ/DS) architecture [10] achieves scalability by aggregating traffic classification state which is conveyed by means of IP-layer packet marking using the DS field. With the DS architecture, sophisticated classification, marking, policing and shaping operations only need to be implemented at network boundaries or hosts. Network resources are allocated to traffic streams by service provisioning policies which govern how traffic is marked and conditioned upon entry to a differentiated services-capable network. Therefore, applications with similar traffic characteristics and performance requirements are mapped into DS service classes – based on end-to-end behaviour requirements of the applications – so they will receive a particular forwarding behaviour along their path.

2.5.1 DS principles and concepts

Due to the importance of the DS architecture within the terms of this thesis, a brief explanation of the basic concepts on DS is presented in this section.

A DS domain consists of a contiguous set of DS nodes that operate with a common service provisioning policy set of Per-Hop-Behavior (PHB) groups implemented on each node. It has a well-defined boundary consisting of DS boundary nodes that classify (and might condition) ingress traffic. Nodes within a DS domain select the packets' forwarding behavior based on their DS Code Point (DSCP), mapping that value into one of the supported PHBs.

The PHB is the means by which a node allocates resources to behaviour aggregates. PHBs may be specified in terms of their resource (e.g., buffer, bandwidth) priority relative to other PHBs, or in terms of their relative observable traffic characteristics (e.g., delay, loss).

Packet classifiers select packets in a traffic stream based on the content of some portion of the packet header. The Behavior Aggregate (BA) Classifier classifies packets based on the DSCP. The classifiers and traffic conditioners are set to reflect the policy and traffic goals for that domain and may be specified in a Traffic Conditioning Agreement (TCA). Once packets have crossed the DS boundary, adherence to DS principles makes it possible to group packets solely according to the behaviour they receive at each hop.

A traffic profile specifies the temporal properties of a traffic stream selected by a classifier. It provides rules for determining whether a particular packet is in-profile or out-of-profile. Different conditioning actions may be applied to the in-profile packets and out-of-profile packets: In-profile packets may be allowed to enter the DS domain without further conditioning; alternatively, their DSCP may be changed. Out-of-profile packets may be queued until they are in-profile, discarded, marked with a new code point or forwarded unchanged.

2.5.2 Per-Hop-Behaviors

The PHB is indicated by encoding the DSCP, which is a six bit value, into the eight bit DS field of the IP packet header. Theoretically this would lead the network to manage up to sixty-four different traffic classes by the means of the DSCP; on the other hand the DS RFCs recommend certain encodings which we will comment in this section. PHB groups usually share a common constraint applying to each PHB within the group, and are implemented in nodes by means of some buffer management and packet scheduling mechanisms.

In Table 2.1 the behaviour that each treatment aggregate should have (according to the DS RFCs) and the DSCP field marking of the packets that should be classified into each of the treatment aggregates is summarized.

Treatment Aggregate	Treat. Ag. Behaviour	DSCP
Network Control	CS (Class Selector)	CS6
Real-Time	EF (Expedited Forwarding)	EF, CS5, AF41, AF42, AF43, CS4, CS3
Assured Elastic	AF (Assured Forwarding)	CS2, AF31, AF21, AF11 AF32, AF22, AF12 AF33, AF23, AF13
Elastic	Default (Best Effort)	Default CS1

Table 2.1: Treatment Aggregate Behaviour

2.5.2.1 Expedited Forwarding (EF)

The intent of Expedited Forwarding [13] PHB is to provide a building block for low-loss, low-delay, and low-jitter services. It can be used to build an enhanced best-effort service: traffic remains subject to loss due to line errors and reordering during routing changes. However, using queuing techniques, the probability of delay or variation in delay is minimized. These characteristics are suitable for voice, video and other real-time services.

2.5.2.2 Assured Forwarding (AF)

Assured Forwarding PHB group [18] is a an enhanced best-effort service that allows a provider DS domain to offer different levels of forwarding assurances for IP packets received from a customer DS domain. Moreover, it allows the operator to provide assurance of delivery as long as the traffic does not exceed some subscribed rate.

Four AF classes are defined, where each AF class is in each DS node allocated a certain amount of forwarding resources (buffer space and bandwidth). Within each AF class IP packets are marked with one of three possible drop precedence values. In case of congestion, the drop precedence of a packet determines the relative importance of the packet within the AF class. An IP packet that belongs to an AF class “i” and has drop precedence “j” is marked with the AF code point AFij, where 1 <= i <= 4 and 1 <= j <= 3. Packets in one AF class are forwarded independently from packets in another AF class. The recommended values of the AF code points are summarized in Table 2.2.

	Class 1	Class 2	Class 3	Class 4
Low Drop Precedence	001010 (AF11)	010010 (AF21)	011010 (AF31)	100010 (AF41)
Medium Drop Precedence	001100 (AF12)	010100 (AF22)	011100 (AF32)	100100 (AF42)
High Drop Precedence	001110 (AF13)	010110 (AF23)	011110 (AF33)	100110 (AF43)

Table 2.2: AF code point values

2.5.2.3 Default Forwarding (DF) or Best Effort (BE)

Best-effort service can be summarized as "I will accept your packets". For the basic best-effort service, a single DSCP value is provided to identify the traffic (the recommended DSCP for the default PHB is '000000'), a queue to store it, and active queue management to protect the network from it and to limit delays.

2.6 Further work on Emergency Services

In [30] the authors discuss the Quality of Service policy to prepare for emergency situations and then classify the traffic based on the character of SIP and media data. In the document the authors concentrate on VoIP traffic (a real-time application) for emergency services. In order to establish a new class of service – specific for emergency sessions– among the ones already offered, they remark the need to clearly differentiate this new class. There are several methods to achieve this goal: relative priority marking, service marking, label switching, integrated Services/RSVP, etc. The one that has been considered for the present work is DS, which the authors of the paper declare to be fundamental for the classification of Internet traffic in order to prepare for emergency conditions (or highly congested conditions). DS has been explained in detail in the previous section within this chapter, but let us clarify that a "service" defines some significant characteristics of packet transmission in one direction across a set of one or more paths within a network. These characteristics may be specified in quantitative or statistical terms of throughput, delay, jitter, and/or loss, or may otherwise be specified in terms of some relative priority of access to network resources. Service differentiation is desired to accommodate heterogeneous application requirements and user expectations, and to permit differentiated pricing of Internet service. For the priority scheduler, the authors recommend Class Based Queuing (CBQ). The paper proposes a call admission procedure based on the flow information and a SIP message log.

In [12] the author reviews the Emergency Telecommunications Services (ETS) requirements, dividing them into two different groups: Deployment-related issues and impact on current and future protocols. The paper also stresses that there are four key areas of general requirements for Emergency Telecommunications Services (ETS) for Internet systems, that is:

- Signaling. If emergency telecommunications is indicated via signaling, it must support the use of labels, e.g., a label may indicate an emergency call.
- Labels. May exist at different layers. Labels may be carried by signaling, and/or as a part of the header of a data packet.
- Policy. Local policy identifies the mechanisms to implement the effects of labels, i.e., labels do not have global significance.
- Network functionality. For ETS, this should be offered as a better than best effort service through a higher probability of reduced packet loss, and/or minimal jitter, and/or minimum end-to-end delay.

Dr. Chandra remarks in his paper the usefulness of DS mechanisms for the priority treatment and expresses his doubts about the success in the use of the SIP priority header for the call control function.

In [4] the 3GPP establishes the service description for emergency services in the IP Multimedia Core Network Subsystem, including the elements necessary to support IP Multimedia emergency services. In [26] the authors propose an extension of the 3GPP IMS emergency services architecture for the provision of enhanced, context-aware emergency services.

In [26] the authors propose an extension of the 3GPP IMS emergency service architecture (described in section 3 within this chapter) in order to lead to more efficient emergency operations. Specifically, they add context management entities: Sensor Gateways (SGW) – which interwork between information sources and the 3G core network – and a Context Information Base (CIB) – responsible of the management and dissemination of the contextual information provided by the first entities –. They also propose enhancements for the LRF, E-CSCF and the PSAP. We want to stress that, in first place, it is work in progress and, at the moment, the proposed architecture slightly differs from the one at FOKUS, so parameters as location will not be taken into account in the present work. In second place there is still a lack of information about the way of defining possible situations within Emergency Services and that leads to the general term Emergency Services, not distinguishing among the different possibilities, although in [27] the authors criticize this fact and propose two new classes to improve the initial model, as well as define different QoS profiles in terms of QoS guarantees based on the needs of emergency communication services. In [27] the authors also propose an extended model for the IMS emergency service architecture, adding two new elements:

the Session Prioritization Function (SPF) – which would make resource allocation/reallocation decisions – and the aforementioned CIB. In this paper [27] the authors propose as well an extension of the main categories of emergency telecommunications (citizen to authority, authority to authority and authority to citizen broadcasting) with a forth category which is “citizen to citizen”, category (considered *urgent* calls among citizens) that would be provided the highest profile defined for regular calls.

In [14] the authors present the use of DS in mobile emergency telemedicine, emphasizing that the DS model fits as an appropriate architecture for QoS provisioning in wireless medical networks. Telemedicine systems demand a highly reliable QoS. Therefore, the authors make a classification of the E-Health QoS requirements that can be contrasted with the characteristics of the different Behavior Aggregates presented in the DS RFCs.

2.7 Conclusions on the related work

The main ideas from the related work that we will be re-using for the development of the thesis are:

- The SIP Priority Header in order to differentiate emergency sessions from non-emergency sessions via signaling
- The DS architecture with the appropriate DSCP assignments, applied to the scope of the thesis as described in section 4.1. Adding the appropriate class definitions that we consider necessary for the priority treatment for both emergency and non-emergency sessions
- The storage of local policies in the PCRF as defined in the PCC architecture [5] for the Call Acceptance Algorithm and traffic management

The points that we consider that are not addressed in the related work and encourage the realization of the thesis are:

- A complementary model to the 3GPP concepts to improve the management of emergency sessions
- A differentiated priority treatment for the diverse classes in the IMS architecture for emergency services [4]
- A bandwidth based Call Acceptance Algorithm managed through local policies for distribution of scheduling
- A clear QCI assignment to the DSCPs in order to differentiate emergency and non-emergency classes
- An scalable model for easy adaption to the specifications of any telecommunications operator

Chapter 3

Objectives and requirements

This chapter presents and establishes the objectives to be reached by the present thesis and discusses the different requirements that the model must respect in order to properly achieve its purpose.

3.1 Objectives

The main objective is to design a scalable model capable of ensuring the Quality of Service of emergency sessions, especially during critical situations with a high rate of emergency calls as the one that we present within the next chapter. The model should be, as well, capable of accepting as many non-emergency sessions as possible under the aforementioned situation. We set a scenario to describe the behavior of the system under a highly stressed situation for the network, study different alternatives and how they affect the performance of the system, and define the main processes of the scalable model.

Considering that there are four categories of emergency telecommunications (including the category introduced in [27] and commented in section 2.6), i.e. *citizen to authority, authority to authority, authority to citizen* and *citizen to citizen* (not included in [25]); we focus in the present thesis in the category *citizen to authority*, which is used by the general public to report problems or difficulties, to learn the state of relatives and properties through specific numbers provided by the government agencies in case of disaster; or to summon help from the authorities. The reasons why we do not treat the other categories within this thesis are:

- *Authority to authority*: Because this category shall have a similar behavior than the *citizen to authority* category, but the authority users are not classified into Gold, Silver and Bronze depending on their Service Level Agreement (SLA) as general public shall be. This category is used by authorities to coordinate efforts during emergency or disaster relief, as well as in mitigation operations.
- *Authority to citizen*: Because this category relies on broadcasting (therefore, it does not need the differentiated classes defined in this thesis). This category is used by government agencies to notify the public when disasters occur or to warn the public about immediate upcoming disasters.
- *Citizen to citizen*: Because this category is not included in [25] and must be treated especially carefully as it has a huge potential for abuse. This category would be used by the general public to learn directly from other citizens (e.g. friends, relatives, employees, etc.) the state of relatives, friends and properties in case of major events (not only disasters).

In the first place we create a new class to identify emergency sessions and differentiate them from all the other classes, which would represent the non-emergency sessions and are described as Bronze, Silver and Gold regarding the service degree contracted by the end-user. DS-based technology is used to provide different treatment to different types of traffic (DS mechanisms treat packets from different applications in a different manner in order to achieve the desired end-user application experience as described in section 2.5).

The detection of emergency sessions is done through a specific header in the SIP signaling. The model takes into account the amount of emergency sessions, so boundaries need to be established (see chapter four) in order to detect the breaking points where non-emergency sessions' quality will be downgraded, new non-emergency sessions will be restricted or, when needed due to the limited bandwidth, non-emergency sessions will be even dropped through specific events in the local policies (designed for distribution of scheduling).

The policies designed may affect differently to Bronze, Silver and Gold users, as Gold users have privileges upon Silver and Bronze users, and Silver users have privileges upon Bronze users. Therefore, one of the goals of the present thesis is to make the existing architecture able to accept as many sessions as possible within the limited resources under a critical situation, but always ensuring prioritized treatment and best Quality of Service possible for emergency sessions.

It is assumed that non-emergency sessions may experience blocking thorough connection admission control procedures, in order to allow for emergency sessions to complete.

The design of the model for emergency services is expected to be complementary to the IMS architecture improvements that are being developed in Fraunhofer Institute FOKUS [15] for the implementation of Emergency Services as described in section 2.3.

3.2 Requirements

The design of the model for Emergency Services in NGNs must respect the general requirements described below in order to accomplish the goals established in the previous section:

- To provide a scalable model for telecommunications operators capable of efficiently supporting emergency and non-emergency services, even under critical emergency situations.
- To accept as many sessions as possible in limited bandwidth.
- To provide high probability of call completion and adequate QoS.
- To distinguish between emergency and non-emergency sessions.
- To provide high quality service for important communications:
    - Emergency sessions: Full QoS support for all media.
    - Normal sessions: Guarantee only minimum quality (see next section).

- Emergency and non-emergency sessions share the same resources. Important sessions should dispatch resources preferentially. Normal sessions should use the remainder of the resources not used by important sessions.
- Emergency sessions need to be treated preferentially compared to non-emergency sessions in order to improve completion rate of the emergency traffic (during the network capacity limited situations).
- To provide a mechanism for distribution of scheduling through the creation of a specific group of policies.
- To reject new sessions and drop or restraint current sessions through events in the local policies.
- Emergency session packets should minimize packet loss, jitter and delay.
- QoS for non-emergency sessions should scale as network resources become available.
- To consider that emergency sessions utilize high bandwidth demanding real-time 3GPP services such as high-quality video, in order to be easily scalable in the near future.

3.2.1 Requirements for the treatment of the sessions

The specific requirements for the treatment of emergency and non-emergency sessions, providing that non-emergency sessions are divided into Gold, Silver and Bronze (where Gold sessions have preferential treatment and priority over Silver and Bronze, as well as Silver over Bronze) are presented below:

- To provide different priority levels not only to emergency and non-emergency sessions, but also to Gold, Silver and Bronze within non-emergency sessions.
- For non-emergency sessions, the number of sessions that can be supported is more important than the quality of each session. This requirement strongly applies to Bronze sessions; for Gold and Silver sessions the quality of each single session is relative to the amount of bandwidth reserved for these kinds of users.
- In a multimedia session it might not be necessary to guarantee quality of all media for normal communications in an emergency situation. Therefore, quality of service and available multimedia services should be downgraded when bandwidth becomes scarce. This requirement will affect, within non-emergency sessions, low priority treatment users in the first place (i.e., this measure will affect Bronze and Silver sessions before it does to Gold sessions).

Chapter 4

Design and Scenario

4.1 Differentiated services in the context of the model

The DS architecture is based on a simple model where traffic entering a network is classified and possibly conditioned at the boundaries of the network, and assigned to different behaviour aggregates. Each behaviour aggregate is identified by a single DS code-point. Packets are classified and marked to receive a particular per-hop forwarding behavior on nodes along their path. A Per-Hop Behavior (PHB) is a description of the externally observable forwarding behavior of a DS node applied to a particular DS aggregate.

PHBs may be specified in terms of their resource (e.g., buffer, bandwidth) priority relative to other PHBs, or in terms of their relative observable traffic characteristics (e.g., delay, loss). These PHBs may be used as building blocks to allocate resources and should be specified as a group (PHB group) for consistency. PHB groups will usually share a common constraint applying to each PHB within the group, such as a packet scheduling or buffer management policy. The relationship between PHBs in a group may be in terms of absolute or relative priority (e.g., discard priority by means of deterministic or stochastic thresholds), but this is not required. The PHBs in the present model are assigned to the QoS Class Identifiers as we indicate below:

- QCI 1: Expedited Forwarding (EF)
- QCI 2: Assured Forwarding 41 (AF41)
- QCI 3: Assured Forwarding 42 (AF42)
- QCI 4: Best Effort (BE)

For real-time applications, the recommended DSCPs are EF, CS5, AF41, AF42, AF43, CS4 and CS3. Therefore, Emergency Services invariably use Expedited Forwarding PHB; Gold subscribers might use either EF or Assured Forwarding (AF41) depending on the circumstances, e.g. this category would downgrade its QCI from EF to AF when required, due to the need of freeing resources in order to provide the appropriate service to emergency sessions. Silver subscribers are assigned to Assured Forwarding (AF42) (although they might be assigned to BE as will be discussed in further sections) and, finally, Bronze users are assigned to Best Effort. The reasons for the choice of the PHB assignments are explained in detail in the next sections.

4.1.1 Per-Hop Behaviours (PHB) assigned to the QCIs

4.1.1.1 Expedited Forwarding (QCI 1)

The intent of the EF PHB is to provide a PHB in which suitably marked packets usually encounter short or empty queues. Furthermore, if queues remain short relative to the buffer space available, packet loss is also kept to a minimum.

To ensure that queues encountered by EF packets are usually short, it is necessary to ensure that the service rate of EF packets on a given output interface exceeds their arrival rate at that interface over long and short time intervals, independent of the load of other (non-EF) traffic.

EF PHB is generally used to carry voice and for transport of data information that requires *wire like* behaviour through the IP network, which is the behaviour expected for the packets assigned to QCI 1 (Emergency Services and Gold subscribers under favourable circumstances, e.g. the load of information can be easily handled by the network). Voice is an inelastic "real-time" application that sends packets at the rate the codec produces them, regardless of availability of capacity. As such, this service has the potential to disrupt or congest a network if not controlled (it also has the potential for abuse).

4.1.1.2 Assured Forwarding (QCI 2, QCI 3)

Assured Forwarding (AF) PHB group provides forwarding of IP packets in 4 independent AF classes. Within each AF class, an IP packet is assigned one of 3 different levels of drop precedence. Packets in one AF class are forwarded independently from packets in another AF class.

AF4x is intended for real-time applications, therefore we will implement AF4 for Silver users in general, as well as for Gold users in particular cases (e.g. when the network needs to downgrade this category QCI in order to free bandwidth resources). In order to establish the appropriate drop precedence within the AF class, QCI 3 (Silver subscribers) is assigned to AF42 and QCI 2 (Gold Subscribers) is assigned to AF41, with a lower level of drop precedence.

4.1.1.3 Best Effort (QCI 4)

A Best Effort PHB is meant for sending *normal internet traffic* across a DS network. That is, the definition and use of this PHB is to preserve, to a reasonable extent, the pre-DS delivery expectation for packets in a DS network that do not require any special differentiation.

Packets in transit may be lost, reordered, duplicated, or delayed at random. Generally, networks are engineered to limit this behaviour, but changing traffic loads can push any network into such a state. Application traffic in the internet that uses default forwarding is expected to be *elastic* in nature; this means that the sender of traffic will adjust its transmission rate in response to changes in available rate, loss, or delay. Therefore, this PHB is assigned *a priori* to Bronze subscribers (QCI 4).

4.1.2 Scheduler

A queue is a data structure that holds packets that are awaiting transmission in routers of the network. The packets may be delayed while in the queue, possibly due to lack of bandwidth, or because they are low in priority. There are a number of ways to implement a queue. A simple model of a queuing system, however, is a set of data structures for packet data, which we will call queues, and a mechanism for selecting the next packet from among them, which we call a scheduler.

A priority queuing system is a combination of a set of queues and a scheduler that empties them in priority sequence. When asked for a packet, the scheduler inspects the highest priority queue and, if there is data present, returns a packet from that queue. Failing that, it inspects the next highest priority queue, and so on.

A priority queue or queuing system needs to avoid starvation of lower-priority queues. This may be achieved through a variety of means, such as admission control, rate control, or network engineering.

The priority scheduler considered for this thesis is Class Based Queuing (CBQ). CBQ is a traffic management algorithm developed by the Network Research Group at Lawrence Berkeley National Laboratory as an alternative to traditional router-based technology, now in the public domain as an open technology.

4.2 Description of the scenario

Functioning and effective telecommunications are fundamental during and after disasters, might be they natural or man-made, and it is especially in these particular situations that communications might congest at a very high rate. Therefore, emergency sessions need to be prioritized over non-emergency sessions to ensure the best coordination. For the more, it becomes clear that the control of Quality of Service in the on-going non-emergency sessions or even the acceptance of new non-emergency sessions is a key feature for the success of emergency services in critical situations.

The scenario that we introduce in the present work consists of an emergency situation in which emergency sessions increase exponentially and set the system under high pressure. Our premise is based on the events occurred in Madrid (explained in detail in the next section), where on March the eleventh 2004 –three days before the elections–, a series of terrorist attacks, with almost ten simultaneous explosions in four trains at rush hour in the morning, caused 191 deaths and 1858 injured.

4.2.1 March the 11th 2004

The terrorist attacks of March the eleventh 2004, also known as 11-M in Spain, consisted of a series of terrorist bombings in four crowded commuter trains at rush hour (between 07.36 and 07.40) in the morning of the aforementioned day. Ten explosions took place, causing 191 deaths and 1858 injured people. Two more bombs were detonated under control, after police failed in trying to deactivate them. A third bomb could be deactivated by the police's bomb disposal experts, its content led to the identification of the authors of the bombings.

The explosive contents had been placed in backpacks and were distributed among different carriages belonging to different trains traveling on the same line and in the same direction between *Alcalá de Henares* and *Atocha* station in Madrid (in the center of the city). The explosions took place as described below:

- Atocha Station: Three bombs exploded between 07.37 and 07.38
- El Pozo del Tío Raimundo Station: Two bombs exploded at 07.38 as the train was starting to leave the station
- Santa Eugenia Station: One bomb exploded at 07.38
- Tellez street: 800 meters away from Atocha Station four bombs exploded in the train at 07.39

The attacks were attributed to a Muslim inspired Al-Qaeda terrorist cell by the *Audiencia Nacional*, although in the first moment the Spanish Government (*Partido Popular*) and some media insisted on the responsibility of ETA (a Basque terrorist group) in the terrorist attacks.

The tragic events took place three days before the Spanish elections and they are said to have changed the citizens' choice in their voting intention, as PP had been first in the poles prior to the terrorist attacks. The ETA lay was understood to be convenient for PP's results in the elections, due to the political party's special commitment against this terrorist group. On the other hand, the Islamic terrorist group lay was clearly against the political party's interest, due to their involvement in the war of Iraq against the public opinion, but convenient for PSOE (*Partido Socialista Obrero Español*, in the opposition at the moment of the terrorist bombings) because they claimed that they would bring the Spanish troops back from Iraq during the electoral process. PP handled the situation in an astonishingly deplorable manner during the three days before the elections, pressing the media to declare that ETA was responsible for the attacks and publicly insulting any political leader who would claim the opposite, when they had already enough information to certainly know that the Islamic lay was much more plausible than the Basque one. The political result was PSOE winning the Spanish elections and the breaking of the Antiterrorist Agreement of 2008 between PP and PSOE.

4.2.2 Premises

The current scenario poses the hypothetical situation that an event similar to the ones described in the previous section would take place in Berlin, implying a coordinated series of terrorist attacks in the train stations of Zoologischer Garten and Hauptbahnhof (where thousands of citizens transit everyday) during rush hour.

Our scenario assumes a population of 3.4 million inhabitants with 2 million IMS subscribers. Moreover, the fact that Madrid has 3.2 million inhabitants and Berlin 3.4, allows a good extrapolation for the proposed scenario.

We consider for the purpose of this thesis a single telecommunications operator. As established and argued in section 3.1, we focus in the *citizen-authority* emergency model among the four main models. The data taken into account to calculate the progression of the system's performance during the different stages of the scenario is the one presented below. We want to remark that real data from operators, based on disaster events such as 9/11, the Madrid terrorist attack and similar incidents is difficult to gather. Therefore, we consider that departing from the data presented we can establish a scalable model for operators based on the reservation of bandwidth.

- Total Bandwidth: 25 Gbytes
- Number of subscribers: 2 millions
- Subscription categories:
    - Gold (15 %): 300,000 subscribers
    - Silver (35 %): 700,000 subscribers
    - Bronze (50 %): 1,000,000 subscribers
- Average traffic rate per category, taking into account Emergency Sessions:
    - Emergency Sessions: 5 %
    - Gold sessions: 20 %
    - Silver sessions: 35 %
    - Bronze sessions: 40 %
- QoS Class Identifiers:
    - QCI 1:
        - Expedited Forwarding (EF)
        - DSCP 1
        - 640 Kb for video
        - 64 Kb for audio
        - Prioritized over QCI 2, 3 and 4
    - QCI 2:
        - Assured Forwarding 41 (AF41)
        - DSCP 2
        - 320 Kb for video
        - 64 Kb for audio
        - Prioritized over QCI 3 and 4
    - QCI 3:
        - Assured Forwarding 42 (AF42)
        - DSCP 3
        - 320 Kb for video
        - 64 Kb for audio
        - Prioritized over QCI 4
    - QCI 4:

- Best Effort (BE)
- DSCP 4
- No video
- 32 Kb for audio

- Prior QCI assignation to subscribers categories and Emergency Sessions:
  - QCI 1: Emergency Sessions and Gold
  - QCI 2: void (Gold when QCI is downgraded for this kind of sessions)
  - QCI 3: Silver
  - QCI 4: Bronze (Silver when QCI is downgraded for this kind of sessions)

Comparing the *subscription categories* with the *average traffic rate per category* we can observe that the distribution of subscribers and the initial distribution of sessions are slightly different. We have assumed that Gold subscribers will tend to establish a larger number of sessions than other subscribers, due to the fact that they have contracted a better service with extended 3GPP capabilities (such as video streaming and videoconference) to the operator – which, consequently, involves a higher price – and wish to enjoy these services that they are paying for.

In the beginning of the scenario there have been no terrorist attacks, the Emergency Sessions' average rate is 5% or lower (5% maximum). As bombs explode in different carriages of different trains, the emergency sessions' rate increases exponentially and as the tragedy is broadcasted in the news, the Emergency Sessions' rate rockets. A side effect to be considered as well is the increase of the networks' occupancy after the broadcasting of the news. Therefore the calculations are presented with different initial occupancies and the variables that increase are both occupancy and emergency sessions' rate. In Table 4.1 we can see the networks' capacity (in users) for each kind of traffic.

QCI	Media Type	Global capacity (users)
1	Video	312,500
	Audio	3,125,000
2	Video	625,000
	Audio	3,125,000
3	Video	625,000
	Audio	3,125,000
4	Video	-
	Audio	6,250,000

Table 4.1: Global Network's capacity (in users) per QCI

Please note that these capacities are calculated as if the whole bandwidth would serve each of the parameters separately, e.g. if we would provide the twenty-five Gigabytes for high-quality audio sessions for QCI 2, then we would be able to serve 3,125,000 sessions. For each QCI we will consider the worst case in terms of bandwidth, meaning that for QCI 1, 2 and 3 we will consider that subscribers request video services (high quality for QCI 1 and 2, and low quality for QCI 3) and for QCI 4 they request audio – as they are not subscribed to any sort of video service. –

Another important feature to remark in the model is the kind of services – requested by the users – related to each kind of session. It is clear that we have considered that each user demands the most expensive bandwidth service contracted (i.e. high-quality video for Gold subscribers, low-quality video for Silver subscribers and low-quality audio for Bronze subscribers). Moreover, we also consider that each emergency session consumes 640 Kbytes bandwidth as they demand high-quality video. There are two main reasons for these considerations: In the first place, we are working with NGNs and we expect that those services which nowadays are minority services (i.e. high-quality videoconferencing or streaming), will become the standard in the near future. Currently, when people talk about emergency services the first image to come into our minds are standard voice calls; however, as videoconferencing shall gradually replace audio calls, the establishment of a videoconference might be much more helpful for the authorities to gather important visual data on the emergency situation. Therefore, we consider this kind of session the standard for emergency services in this thesis. In the second place, considering the worst case (in terms of bandwidth) for each session lowers the maximum capacity of the system in terms of maximum number of sessions supported, but at the end of the scenario we reconvert *number of sessions* into *bandwidth*, meaning that from this point on, if subscribers use less bandwidth-consuming services (as it certainly is in reality), the system is able to absorb a much greater number of sessions than the ones presented at the end of this section (which, indeed, would be the minimum occupancies that the system is capable of offering).

In the worst possible case, the maximum bandwidth that we consider for ES is the 80% of the network's capacity, which in terms of sessions (considering high-quality video) would mean 250,000 sessions. Therefore, we reserve 20% bandwidth under the aforementioned circumstances in order to provide a minimum service for non-emergency calls.

4.2.3 Methodology

In this section we describe the methodology used in the next sections for the study of the scenario's evolution and the system's performance, in order to facilitate the comprehension of the data, analysis and results presented.

We depart from different initial occupancies (by *occupancy* we refer to the percentage of subscribers that currently have a session established over the total number of subscribers: "number of sessions"/"number of subscribers") characterized by the *average traffic rate per category* (meaning a distribution of the on-going sessions into: 5% emergency sessions, 20% Gold sessions, 35% Silver sessions and 40% Bronze sessions, see section 4.2.2 for further details). We have assumed that under standard circumstances (e.g. no terrorist attack has taken place yet) the maximum percentage of emergency sessions over the total number of on-going sessions is 5% and we depart in all the initial statistics from such percentage in order to perform the analysis. Therefore, in section 4.3.1 (the disaster event has not yet occurred) we assume that we have the aforementioned maximum of 5% emergency sessions (over the total number of sessions) and increase the current occupancy (more subscribers establish new sessions) as we maintain the distribution of the sessions. By these means we can check what is the bandwidth required (on the whole and by each category) for certain occupancies, as well as the maximum occupancy that the system is able to support.

In section 4.3.2 we assume that the terrorist attack has occurred and, therefore, we progressively increase the percentage of emergency sessions (redistributing the other percentages) over the whole number of on-going sessions. The effect of this increase in the emergency sessions is studied with different occupancies (e.g. we consider that the total number of sessions is constant, but the increase of emergency sessions affects the distribution of the rest of categories; and we consider as well that the increase of emergency sessions implies an increase in the total number of sessions). By these means we study the performance of the network and requirements of the subscribers when the rate of emergency sessions increases, the occupancy increases or both increase at the same time. We do as well observe when the system reaches the maximum capacity in terms of bandwidth and study the consequences of applying different strategies in order to improve the system's performance.

In section 4.3.3 we assume a panic situation, when requests for emergency services have increased exponentially. One more time we depart from different occupancies (that can be considered to be constant in time or increase along with the emergency sessions) and study how the increase of emergency sessions affects the system's performance and the distribution of the rest of categories. Different strategies and their consequences are studied in order to improve the performance of the system.

In section 4.4 we take into consideration the outcomes of the study of the evolution of the scenario (which reflects the expected resources/bandwidth required by the subscribers under the evolving scenario) in order to determine the thresholds that will activate the appropriate QoS rules (the thresholds are based on the bandwidth reserved for emergency services) and seek the best distribution of the remaining resources among the non-emergency classes.

Finally, in section 4.5 we reconvert the *maximum occupancies* (meaning maximum number of users supported by the system within a certain class over the total number of users of that class) into bandwidth reserved for each category. This feature (as commented on section 4.2.2) allows the system to support many more sessions – working with real data – as most subscribers will not be using the most bandwidth-expensive service available.

In Appendix B the extended tables can be found, which include results that show extensively how the analysis was done for obtaining the presented results.

4.3 Evolution of the scenario and network's performance

4.3.1 Standard situation. 5% rate of Emergency Sessions

In the first place, we will study the network's performance in terms of how variations in subscribers' occupancy affect the bandwidth's demand, increasing progressively the rate of emergency sessions in the following sections.

The tables represent the distribution of the sessions' categories, showing the number of sessions implied per category and the percentage that they represent over the whole amount of on-going sessions. The following tables also present the bandwidth per session required (it is important to remind that we consider the worst possible case per category, meaning that each user would use the most bandwidth expensive service available in his subscription). The tables finally present the bandwidth required for supporting the on-going sessions of each category (in percentage relative to the twenty-five gigabytes available).

4.3.1.1 Occupancy: 20% of the subscribers

With occupancy of 20% the network is supporting 400,000 sessions. In terms of the average rates considered in the premises, this would turn into the numbers presented in Table 4.2 (below).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	20,000	640	2	6.40%
Gold, 1	20%	80,000	640	6	25.60%
Silver, 3	35%	140,000	320	6	22.40%
Bronze, 4	40%	160,000	32	1	2.56%
TOTAL	100%	400,000		**14**	56.96%

Table 4.2: 20% Population's occupancy, 5% Emergency Sessions

As we can see, the network can absorb all the sessions without any further problems, using 56.96% of the total bandwidth. Variations in the percentage of sessions per category (within two million users) can be, *a priori,* easily handled by the network.

4.3.1.2 Occupancy: 25% of the subscribers

With occupancy of 25%, the network is now supporting half a million sessions. Such an amount of sessions, under the premises previously established, would translate into the statistics presented in Table 4.3 (below).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	25,000	640	2	8.00%
Gold, 1	20%	100,000	640	8	32.00%
Silver, 3	35%	175,000	320	7	28.00%
Bronze, 4	40%	200,000	32	1	3.20%
TOTAL	100%	500,000		**18**	71.20%

Table 4.3: 25% Population's occupancy, 5% Emergency Sessions

We can conclude that up to this point the network is still perfectly capable of supporting all the subscribers who request any kind of session, although it is remarkable the fact that, comparing Table 4.2 and Table 4.3, we need approximately 15% more bandwidth to support 5% more users (56.96% necessary for 20% occupancy against 71.20% required for supporting 25% occupancy).

4.3.1.3 Occupancy: 30% of the subscribers

With occupancy of 30% the network is, at this stage, giving service to 600,000 subscribers. In terms of the average rates considered, the results are presented in Table 4.4 (below).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	30,000	640	2	9.60%
Gold, 1	20%	120,000	640	10	38.40%
Silver, 3	35%	210,000	320	8	33.60%
Bronze, 4	40%	240,000	32	1	3.84%
TOTAL	100%	600,000		**21**	85.44%

Table 4.4: 30% Population's occupancy, 5% Emergency Sessions

We can observe the phenomenon that as the occupancy slightly increases; the bandwidth quickly appears to rush to its limit.

4.3.1.4 Occupancy: 35% of the subscribers

With occupancy of 35%, the network is supporting 700,000 sessions. Table 4.5 (below) summarizes the results of the network's performance under the aforementioned circumstances.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	35,000	640	3	11.20%
Gold, 1	20%	140,000	640	11	44.80%
Silver, 3	35%	245,000	320	10	39.20%
Bronze, 4	40%	280,000	32	1	4.48%
TOTAL	100%	700,000		**25**	99.68%

Table 4.5: 35% Population's occupancy, 5% Emergency Sessions

At this point two facts are remarkable. The first one is that with the current occupancy and distribution in the percentage of sessions, the network has reached its limit; therefore, from this moment on, we should strongly consider new strategies to provide service to as many subscribers as possible, but providing the appropriate priority to Gold and Silver accounts. The second fact is that Emergency Services already utilize 11.2% of the bandwidth resources; we can predict that with a different distribution of ES over the whole amount of on-going sessions (e.g. higher than 5%) the bandwidth's demand for this kind of service will quickly involve most of the available bandwidth.

4.3.1.5 Occupancy: 40% of the subscribers

With 40% occupancy, the network would support 800,000 sessions. Considering the premises proposed this implies the statistics presented in Table 4.6 (below).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	40,000	640	3	12.80%
Gold, 1	20%	160,000	640	13	51.20%
Silver, 3	35%	280,000	320	11	44.80%
Bronze, 4	40%	320,000	32	1	5.12%
TOTAL	100%	800,000		**28**	113.92%

Table 4.6: 40% Population's occupancy, 5% Emergency Sessions

At this point, the network is not capable of absorbing the traffic generated by the subscribers anymore. Besides, the network becomes very sensitive to variations in the percentage of sessions per category (especially QCI 1), as it will be more clearly noticed in the following sections. In Table 4.7 (below), Gold users' QCI is downgraded in order to detect the possible improvements in the network's performance.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	40,000	640	3	12.80%
Gold, 2	20%	160,000	320	6	25.60%
Silver, 3	35%	280,000	320	11	44.80%
Bronze, 4	40%	320,000	32	1	5.12%
TOTAL	100%	800,000		**22**	88.32%

Table 4.7: 40% Population's occupancy, 5% Emergency Sessions, QCI 2 for Gold subscribers

These results evince the relief that implies for the network the change proposed for Gold accounts that establish a session; consequently, this option proves to be considerably useful for the purpose pursued.

Please note that with the statistics presented in Table 4.6 and Table 4.7, the network is serving 53.33% of the Gold subscribers (160,000 subscribers out of 300,000) and 40% of the Silver subscribers (280,000 out of 700,000). In particular, this feature demonstrates that the most valuable subscribers for our hypothetical operator can be provided the expected requested services, even under the terms of high-rate occupancies.

4.3.1.6 Summary

Chart 4.1 (below) introduces the percentage of bandwidth needed by the different types of subscribers -including emergency sessions- under the occupancies studied in section 3.1. As commented in the previous sections, it is clearly observable that the network needs to establish certain mechanisms to absorb the traffic when, with 5% of ES, occupancy reaches 30%.

Another feature that can be remarked through the analysis of the chart is the increase of bandwidth used by Gold and Silver subscribers. With occupancy 20% Gold subscribers need approximately 25% of the bandwidth, whereas with occupancy 40% they need half the whole bandwidth. However, when downgrading Gold subscribers' QCI, we observe that the bandwidth required lowers to 25%. Moreover, as we have not yet assumed any changes for Silver subscribers, up to this point the bandwidth that they require approximately doubles the one assigned for Gold accounts.

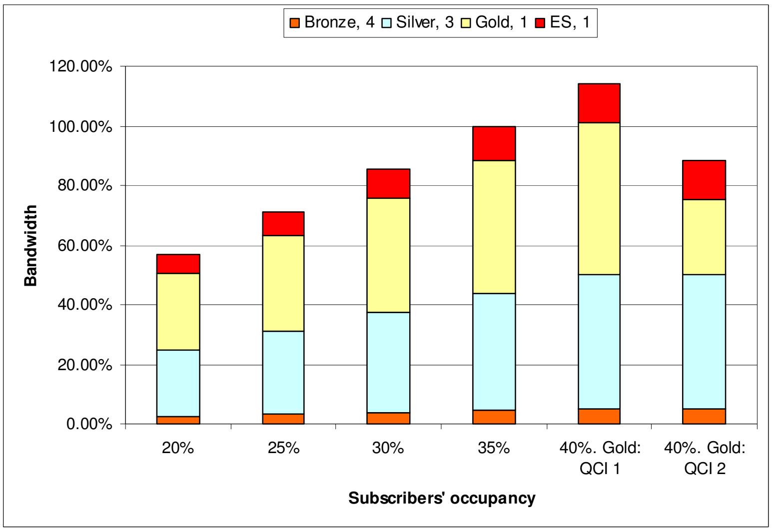

Chart 4.1: 5% Emergency Sessions

Regarding ES, we can appreciate an increase in the bandwidth required. For the more, although the percentage of bandwidth is roughly comparable to the one that Gold and Silver subscribers need, it is noticeable that this increase is not negligible at all. The increase of bandwidth requirements for Bronze sessions is observable, but apparently not especially relevant compared to the bandwidth that the rest of categories need for the proper service of their sessions.

4.3.2 The terrorist attacks take place. Increase in the rate of Emergency Sessions

At this stage, we consider in our scenario that the bombs begin to explode in different trains arriving or departing from Zoologischer Garten and Hauptobahnhof. Chaos and panic reign in the stations and in the whereabouts and citizens begin to call the authorities, either to alert them about the situation, to request for help or to ask for or provide information. The situation is completely chaotic and request for ES increases every single minute, even when authorities are already aware of the situation, people will keep contacting them because of a wide number of possible reasons.

We have considered steps of 5% in the increase of ES. Due to the distribution of the subscribers' categories, this increment involves a decrement of 1% for Gold subscribers and a 2% in both Silver and Bronze subscribers (see Appendix A). At this point, we pose the establishment of emergency sessions up to 20% of the current sessions, studying the effect on the network's available bandwidth.

4.3.2.1 Occupancy: 20% of the subscribers

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	40,000	640	3	12.80%
Gold, 1	19%	76,000	640	6	24.32%
Silver, 3	33%	132,000	320	5	21.12%
Bronze, 4	38%	152,000	32	1	2.43%
TOTAL	100%	400,000		**15**	60.67%
ES, 1	15%	60,000	640	5	19.20%
Gold, 1	18%	72,000	640	6	23.04%
Silver, 3	31%	124,000	320	5	19.84%
Bronze, 4	36%	144,000	32	1	2.30%
TOTAL	100%	400,000		**16**	64.38%
ES, 1	20%	80,000	640	6	25.60%
Gold, 1	17%	68,000	640	5	21.76%
Silver, 3	29%	116,000	320	5	18.56%
Bronze, 4	34%	136,000	32	1	2.18%
TOTAL	100%	400,000		**17**	68.10%

Table 4.8: 20% Population's occupancy, 10% to 20% Emergency Sessions

The network can absorb the traffic, but the bandwidth required to sustain ES has increased substantially, employing a fourth part of the total resources. We can expect that as the number of sessions established increases, bandwidth will become a scarce resource.

4.3.2.2 Occupancy: 25% of the subscribers

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	50,000	640	4	16.00%
Gold, 1	19%	95,000	640	8	30.40%
Silver, 3	33%	165,000	320	7	26.40%
Bronze, 4	38%	190,000	32	1	3.04%
TOTAL	100%	500,000		**19**	75.84%
ES, 1	15%	75,000	640	6	24.00%
Gold, 1	18%	90,000	640	7	28.80%
Silver, 3	31%	155,000	320	6	24.80%
Bronze, 4	36%	180,000	32	1	2.88%
TOTAL	100%	500,000		**20**	80.48%
ES, 1	20%	100,000	640	8	32.00%
Gold, 1	17%	85,000	640	7	27.20%

Silver, 3	29%	145,000	320	6	23.20%
Bronze, 4	34%	170,000	32	1	2.72%
TOTAL	100%	500,000		**21**	85.12%

Table 4.9: 25% Population's occupancy, 10% to 20% Emergency Sessions

Table 4.9 (above) shows that the network is capable of sustaining a fourth part of the subscribers, with a fifth part of them requesting emergency services. These results are encouragingly satisfactory, although from this moment on it becomes increasingly difficult to maintain the QoS for all sessions.

4.3.2.3 Occupancy: 30% of the subscribers

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	60,000	640	5	19.20%
Gold, 1	19%	114,000	640	9	36.48%
Silver, 3	33%	198,000	320	8	31.68%
Bronze, 4	38%	228,000	32	1	3.65%
TOTAL	100%	600,000		**23**	91.01%
ES, 1	15%	90,000	640	7	28.80%
Gold, 1	18%	108,000	640	9	34.56%
Silver, 3	31%	186,000	320	7	29.76%
Bronze, 4	36%	216,000	32	1	3.46%
TOTAL	100%	600,000		**24**	96.58%
ES, 1	20%	120,000	640	10	38.40%
Gold, 1	17%	102,000	640	8	32.64%
Silver, 3	29%	174,000	320	7	27.84%
Bronze, 4	34%	204,000	32	1	3.26%
TOTAL	100%	600,000		**26**	102.14%

Table 4.10: 30% Population's occupancy, 10% to 20% Emergency Sessions

In Table 4.10 (above), we can appreciate the fact that the network reaches its capacity limit, as well as the fact that ES are consuming almost 40% of the bandwidth. Considering the option of changing Gold subscribers' QCI from one to two (with priority over Silver subscribers), downgrading video quality from 640 Kbps to 320 Kbps, the network can be considerably relieved as we can see in Table 4.11 (below).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	120,000	640	10	38.40%
Gold, 2	17%	102,000	320	4	16.32%
Silver, 3	29%	174,000	320	7	27.84%
Bronze, 4	34%	204,000	32	1	3.26%
TOTAL	100%	600,000		**21**	85.82%

Table 4.11: 30% Population's occupancy, QCI 2 for Gold subscribers

Applying the QCI change for Gold subscribers we can free around 16% of the bandwidth resources, which are highly valuable for incoming sessions, especially in the case of Bronze subscribers. It is especially interesting to point out that we are downgrading QCI when ES represent 38.4% of the bandwidth, this fact will be useful when establishing the bandwidth margins and the policies in following sections.

4.3.2.4 Occupancy: 35% of the subscribers

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	70,000	640	6	22.40%
Gold, 1	19%	133,000	640	11	42.56%
Silver, 3	33%	231,000	320	9	36.96%
Bronze, 4	38%	266,000	32	1	4.26%
TOTAL	100%	700,000		**27**	106.18%
ES, 1	15%	105,000	640	8	33.60%
Gold, 1	18%	126,000	640	10	40.32%
Silver, 3	31%	217,000	320	9	34.72%
Bronze, 4	36%	252,000	32	1	4.03%
TOTAL	100%	700,000		**28**	112.67%
ES, 1	20%	140,000	640	11	44.80%
Gold, 1	17%	119,000	640	10	38.08%
Silver, 3	29%	203,000	320	8	32.48%
Bronze, 4	34%	238,000	32	1	3.81%
TOTAL	100%	700,000		**30**	119.17%

Table 4.12: 35% Population's occupancy, 10% to 20% Emergency Sessions

The statistics in Table 4.12 (above) clearly show that with the current distribution the network is above its capacity, one possible solution would be to begin dropping sessions or not accepting new sessions according to the appropriate call acceptance algorithm. However, if we apply the QCI change from 1 to 2 for Gold users, we can expect a significant mitigation of the bandwidth's usage.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	105,000	640	8	33.60%
Gold, 2	18%	126,000	320	5	20.16%
Silver, 3	31%	217,000	320	9	34.72%
Bronze, 4	36%	252,000	32	1	4.03%
TOTAL	100%	700,000		**23**	92.51%
ES, 1	20%	140,000	640	11	44.80%
Gold, 2	17%	119,000	320	5	19.04%
Silver, 3	29%	203,000	320	8	32.48%
Bronze, 4	34%	238,000	32	1	3.81%
TOTAL	100%	700,000		**25**	100.13%

Table 4.13: 35% Population's occupancy, QCI 2 for Gold subscribers

In Table 4.13 (above), we can appreciate that the network's performance improves consistently. Regarding these results, the QCI change for Gold users seems to be a good option, despite the downgrade of high quality video to low quality video for the aforementioned subscribers. For the more, applying this feature reduces in half the percentage of bandwidth used by Gold subscribers, allowing Silver subscribers to use a higher percentage of the network's bandwidth resources (although we could presume that the rest of the bandwidth could be reserved for Gold accounts). In the last section, we downgraded QCI when ES occupied 38.4% of the bandwidth, here we can see that this change is considered at the point when ES use 33.6% of the network's bandwidth.

We have to consider that there are 42.86% more Silver subscribers than Gold ones (e.g. 300,000 Gold subscribers and 700,000 Silver subscribers), as well as the fact that allowing as many sessions as possible is one of the actual goals. However, we cannot penalize Gold users upon Silver and Bronze, as Gold users are considered the most valuable for our operator; consequently, even if we assign more bandwidth resources to Silver accounts than to Gold ones, a greater percentage of Gold subscribers should be able to establish a session than Silver or Bronze users (e.g. Gold subscribers must get a better service from the operator than the rest, as well as Silver must get a better service than Bronze). Providing higher bandwidth to Silver accounts than to Gold ones does not mean that Gold users will get a lower relative potential occupancy, due to the aforementioned fact that there are 42.86% more Silver than Gold subscribers; in other words, for supporting the same percentage of both kind of users, Silver would require a higher amount of bandwidth than Gold subscribers.

4.3.2.5 Occupancy: 40% of the subscribers

To this extent the statistics present some interesting results to be taken into consideration. Nevertheless, with occupancy 40% of the subscribers using the IMS Network the resources become very scarce as we can observe in Table 4.14 (below).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	80,000	640	6	25.60%
Gold, 1	19%	152,000	640	12	48.64%
Silver, 3	33%	264,000	320	11	42.24%
Bronze, 4	38%	304,000	32	1	4.86%
TOTAL	100%	800,000		**30**	121.34%
ES, 1	15%	120,000	640	10	38.40%
Gold, 1	18%	144,000	640	12	46.08%
Silver, 3	31%	248,000	320	10	39.68%
Bronze, 4	36%	288,000	32	1	4.61%
TOTAL	100%	800,000		**32**	128.77%
ES, 1	20%	160,000	640	13	51.20%
Gold, 1	17%	136,000	640	11	43.52%
Silver, 3	29%	232,000	320	9	37.12%
Bronze, 4	34%	272,000	32	1	4.35%
TOTAL	100%	800,000		**34**	136.19%

Table 4.14: 40% Population's occupancy, 10% to 20% Emergency Sessions

In terms of absolute bandwidth, the increase of emergency sessions leads to the overload of the network. Even considering the QCI downgrade for Gold users does not solve the problem, as shown in Table 4.15 (below). In order to offer the best performance of the network, call admission methods have to be established, as well as even session dropping under the worst circumstances.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	120,000	640	10	38.40%
Gold, 2	18%	144,000	320	6	23.04%
Silver, 3	31%	248,000	320	10	39.68%
Bronze, 4	36%	288,000	32	1	4.61%
TOTAL	100%	800,000		**26**	105.73%
ES, 1	20%	160,000	640	13	51.20%
Gold, 2	17%	136,000	320	5	21.76%
Silver, 3	29%	232,000	320	9	37.12%
Bronze, 4	34%	272,000	32	1	4.35%
TOTAL	100%	800,000		**29**	114.43%

Table 4.15: 40% Population's occupancy, QCI 2 for Gold subscribers

4.3.2.6 Summary

The two following charts summarize the bandwidth statistics presented along section 4.3.2. Chart 4.2 (below) arranges the data under "Occupancy – Emergency Services' rate", gathering in first place the network's occupancy. Therefore, we can observe how the distribution within the categories varies from each group of occupancies to the next one. Anyhow, it is interesting to emphasize that, even if these distributions seem irregular along the different occupancies, the total bandwidth required increases consistently through the graphic.

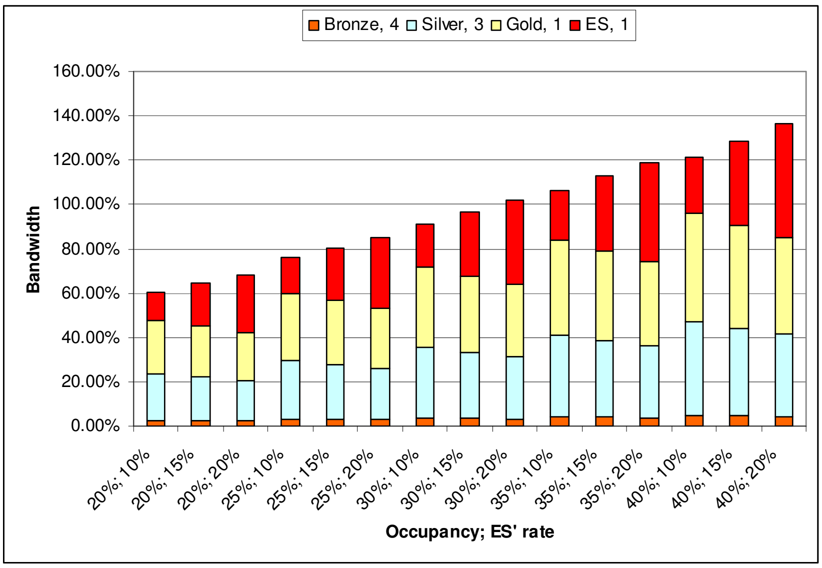

Chart 4.2: 10%-20% Emergency Sessions

The chart shows that the bandwidth requirements for Bronze subscribers remain very low along the sample. Gold subscribers and ES experiment the greatest variations in the bandwidth requirements, especially ES as it can only grow at expenses of the other categories. Another feature, already commented in section 4.3.2.3, is that at "*30%; 20%*" the bandwidth is not sufficient to handle the expected amount of sessions. Therefore, in Chart 4.3 (below), we present the new results applying the QCI downgrade for Gold subscribers.

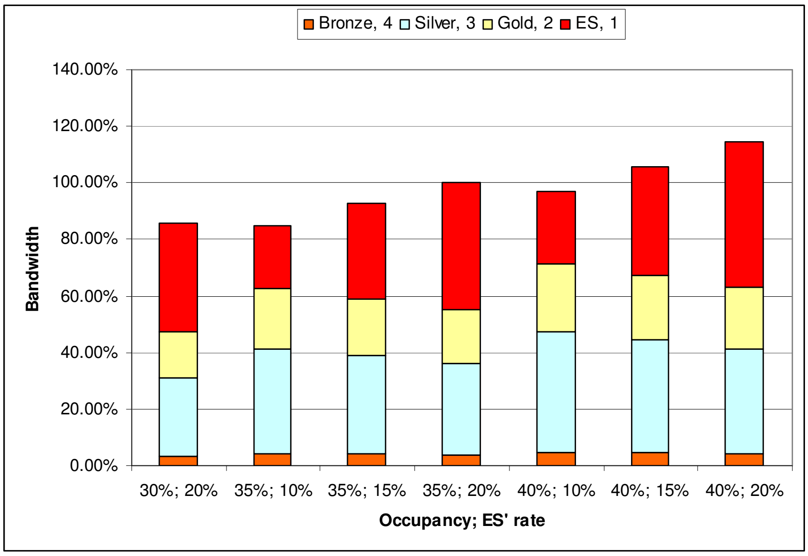

Chart 4.3: 10%-20% Emergency Sessions, QCI 2 for Gold subscribers

As the graphical data demonstrates – comparing Chart 4.2 and Chart 4.3 – the network can perform much better after the QoS change. However, under certain circumstances (e.g. occupancy 40% and ES' rate equal or higher than 15%) this measure proves insufficient in order to achieve our goal of serving as many sessions as possible, due to the fact that we surpass the total amount of bandwidth available. It is particularly interesting to compare the change in the bandwidth employed by Gold subscribers in both charts; we can observe as well that the rest of bandwidths remain the same. In the following sections we will see how difficult is to maintain the amount of sessions expected.

4.3.3 The media broadcasts the terrorist attacks. Emergency Sessions cumulate the network's bandwidth

In this section, we consider in our scenario that the media has broadcasted the dreadful news. The reaction of the citizens is immediate: they try to contact their relatives, call the emergency numbers established for identification of the possible victims, call the authorities for any suspicious bag or person they might see anywhere, etc. The effect caused by these reactions in the network is mainly the rocketing of ES. Anyhow, the study that we present assumes that the maximum bandwidth that can be reserved for ES is 80% the total bandwidth. The amount of users that can be sustained under this premise is 250,000, as we already commented in section 4.1.

The tables in the following sections introduce the evolution of the network's performance, comparing different rates of emergency sessions (beginning at 30% of the whole amount of on-going sessions) with the upper-limit of 250,000 emergency-session users (which reflects in different percentages regarding the total number of on-going sessions) which is meant to be the number of allowed emergency sessions when reserving 80% bandwidth for this purpose.

4.3.3.1 Occupancy: 20% of the subscribers

Table 4.16 (below) shows that with 20% occupancy the Network is capable of dealing with high rates of ES requests. Anyhow, when the maximum bandwidth reserved for ES is reached, we find out that almost one hundred per cent of the resources are being used, meaning that slight variations in the occupancy's distribution might collapse the network.

Regarding the column "percentage of sessions" within Table 4.16 (below), it is remarkable the fact that, with the current occupancy (e.g. 400,000 sessions, 20% of the whole amount of subscribers), the network is able to support 62.5% of the on-going sessions as emergency ones (which is a very high rate).

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	120,000	640	10	38.40%
Gold, 1	15%	60,000	640	5	19.20%
Silver, 3	25%	100,000	320	4	16.00%
Bronze, 4	30%	120,000	32	0	1.92%
TOTAL	100%	400,000		**19**	75.52%
ES, 1	**62.50%**	250,000	640	20	80.00%
Gold, 1	8.50%	34,000	640	3	10.88%
Silver, 3	12.00%	48,000	320	2	7.68%
Bronze, 4	17.00%	68,000	32	0	1.09%
TOTAL	100.00%	400,000		**25**	99.65%

Table 4.16: 20% Population's occupancy, 30% to 62.5% Emergency Sessions

4.3.3.2 Occupancy: 25% of the subscribers

As shown in Table 4.17 (below), the network has difficulties maintaining the service for the on-going sessions. It would barely be able to accept new incoming sessions as well. Therefore, in Table 4.18 (below) Gold users' QCI is downgraded to analyze the impact on the bandwidth. The results demonstrate that this measure is not enough with the current number of emergency sessions.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	150,000	640	12	48.00%

Gold, 1	15%	75,000	640	6	24.00%
Silver, 3	25%	125,000	320	5	20.00%
Bronze, 4	30%	150,000	32	1	2.40%
TOTAL	100%	500,000		**24**	94.40%

ES, 1	40%	200,000	640	16	64.00%
Gold, 1	13%	65,000	640	5	20.80%
Silver, 3	21%	105,000	320	4	16.80%
Bronze, 4	26%	130,000	32	1	2.08%
TOTAL	100%	500,000		**26**	103.68%

ES, 1	50%	250,000	640	20	**80.00%**
Gold, 1	11%	55,000	640	4	17.60%
Silver, 3	17%	85,000	320	3	13.60%
Bronze, 4	22%	110,000	32	0	1.76%
TOTAL	100%	500,000		**28**	112.96%

Table 4.17: 25% Population's occupancy, 30% to 50% Emergency Sessions

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	200,000	640	16	64.00%
Gold, 2	13%	65,000	320	3	10.40%
Silver, 3	21%	105,000	320	4	16.80%
Bronze, 4	26%	130,000	32	1	2.08%
TOTAL	100%	500,000		**23**	93.28%

ES, 1	50%	250,000	640	20	**80.00%**
Gold, 2	11%	55,000	320	2	8.80%
Silver, 3	17%	85,000	320	3	13.60%
Bronze, 4	22%	110,000	32	0	1.76%
TOTAL	100%	500,000		**26**	104.16%

Table 4.18: 25% Population's occupancy, QCI 2 for Gold subscribers

As previously commented, we ascertain that reserving 80% of the bandwidth is not a simple task anymore. In section four, we will establish further measures in order to make the network capable of dealing with any possible upcoming situation within our scenario.

4.3.3.3 Occupancy: 30% of the subscribers

In the present context, we can detect in Table 4.19 (below) the fact that the current distribution exceeds the available bandwidth and, since in the previous section we have found out that downgrading the QoS parameters for Gold users is not sufficient at this point, we can assume that any higher occupancy will exceed in great measure the network's bandwidth capacity. Therefore, from this stage on there is no need to set out higher occupancies.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	180,000	640	14	57.60%

Gold, 1	15%	90,000	640	7	28.80%
Silver, 3	25%	150,000	320	6	24.00%
Bronze, 4	30%	180,000	32	1	2.88%
TOTAL	100%	600,000		**28**	113.28%

ES, 1	41.67%	250,000	640	20	80.00%
Gold, 1	12.67%	76,000	640	6	24.32%
Silver, 3	20.33%	122,000	320	5	19.52%
Bronze, 4	25.33%	152,000	32	1	2.43%
TOTAL	100.00%	600,000		**32**	126.27%

Table 4.19: 30% Population's occupancy, 30% to 41.67% Emergency Sessions

In conclusion, we can state that there is a need to drop sessions, stop accepting new sessions (if bandwidth is not freed) and establishing which percentages should be appropriate, in order to not to penalize Gold users against Silver users.

4.4 Study of bandwidth margins

In the following sections, we will consider as main parameter the distribution of the bandwidth per categories. Departing with an established percentage for emergency sessions, we will study how it affects the rest of the subscribers. The results will define the thresholds implemented in the acceptance algorithm.

4.4.1 Low rate of emergency sessions

In section 4.3.1, we studied the effect of different occupancies on the bandwidth, assuming an average distribution that represents the situation in the scenario before the explosion of the bombs. Considering 700,000 sessions' occupancy with 5% dedicated to ES (35,000 emergency sessions), we found out in section 4.3.1.4 that the network was employing almost one hundred per cent of the bandwidth. In fact, with a slight increase of either occupancy or emergency sessions, the bandwidth's demand raises very quickly as shown in 4.3.1.4 and 4.3.1.5. Therefore, the first margin established is the most critical because it will define the most utilized threshold, even needed under no exceptional circumstances (i.e. raise in the occupancy over 35%). Taking the aforementioned considerations into account and particularly the statistics in Table 4.5, the results suggest reserving 11.2% of the bandwidth for ES before taking any further measures, in emergency sessions this percentage translates into 35,000 sessions.

The next step is to determine the bandwidth assigned for the rest of categories, i.e. Gold, Silver and Bronze. For the pursued goal we will consider that Gold users must be able to establish, proportionally to their number, a higher percentage of sessions than Silver ones, as well as Silver must be able to establish a higher percentage of sessions than Bronze. Departing from the commented results in section 4.3.1, we could expect that the maximum occupancy would turn out to be 35%; however, by redistributing the remaining bandwidth it is possible to improve this feature as Table 4.20 (below) demonstrates, keeping as well the restriction considered at this particular stage of not penalizing higher accounts over lower ones. The column "*% of category*" in ES is referred to the total number of subscribers.

Category	BW reserved	bps	Subscribers supported	% of category
ES, 1	11.20%	640000	35,000	1.75%
Gold, 1	40.00%	640000	125,000	41.67%
Silver, 3	42.80%	320000	267,500	38.21%
Bronze, 4	6.00%	32000	375,000	37.50%
TOTAL	100.00%		802,500	**40.13%**

Table 4.20: 11.2% bandwidth for ES

The fact that more bandwidth is assigned to Silver users than to Gold is because there is a larger number of this kind of accounts. On the other hand, Table 4.20 shows that even if Silver users are provided with more bandwidth, the relative percentage of maximum sessions is higher for Gold subscribers, respecting the requirement established above.

4.4.2 Increase in the bandwidth necessary for supporting ES

In this section, we consider that the request for ES grows over the previously established limit and, therefore, the new necessary bandwidth limit must be defined. In fact, we consider two breaking points to better adapt to the requirements of the subscribers. In order to adjust the network's performance quickly depending on the situation, the first margin must permit a wider variation in the distribution of sessions when occupancy is low and a narrower variation when occupancy is high.

Revising section 4.3.2, we can conclude that the next threshold must be defined by a bandwidth limit of 25.6%. With this selection, we can absorb up to a 20% of emergency sessions under 20% occupancy and 10% with 40% occupancy, as Table 4.8 and Table 4.14 reflect (in the column *% Total Bandwidth* for *Category* "ES"). One inconvenient is that the network will not be able to support 40% occupancy at this stage, as the total bandwidth required in Table 4.14 (section 4.3.2.5) manifests (the maximum occupancy supported will be 35.78%). Actually, the most suitable distribution of the bandwidth for the purposes of this thesis is the one presented in Table 4.21 (below), as it reaches a compromise between the number of users supported, the occupancy for each category and the requirement that Gold users receive better service than Silver and Bronze, and Silver than Bronze (therefore, the maximum occupancy is higher for Gold, medium for Silver and lower for Bronze).

Category	BW reserved	bps	Subscribers supported	% of category
ES, 1	25.60%	640000	80,000	4.00%
Gold, 1	33.60%	640000	105,000	35.00%
Silver, 3	35.90%	320000	224,375	32.05%
Bronze, 4	4.90%	32000	306,250	30.63%
TOTAL	100.00%		715,625	**35.78%**

Table 4.21: 25.6% bandwidth for ES

Indeed, the maximum occupancy will be 35.78%, below 40% as we already expected. Please note that higher categories have a better probability to establish a session successfully, as was already pointed in the previous section.

In the case that more than four per cent of the total subscribers intend to use an ES, the threshold is reached and will change to the next bandwidth distribution, reserving at this point 40% of the bandwidth for ES. It is presumable that at this stage something exceptional (i.e. a major emergency situation) has happened, as it is the case in our scenario.

Category	BW reserved	bps	Subscribers supported	% of category
ES, 1	40%	640000	125,000	6.25%
Gold, 1	26%	640000	81,250	27.08%
Silver, 3	30%	320000	187,500	26.79%
Bronze, 4	4%	32000	250,000	25.00%
TOTAL	100%		643,750	32.19%

Table 4.22: 40% bandwidth for ES, QCI 1 for Gold subscribers

Table 4.22 (above), shows that the percentage of supportable sessions has been considerably lowered. Anyhow, at the point that 40% of the bandwidth for ES is needed, changing the QCI from one to two for Gold users should be considered. The consequences are that video for Gold accounts has been reduced from high-quality to low-quality, achieving similar QoS parameters to Silver subscribers, but maintaining higher priority and a lower drop probability than the aforementioned subscribers (by using a different category within the same AF class). Another consequence is that by these means the network frees an extra 13% of the bandwidth that can be redistributed among the categories, making it possible to achieve better occupancy rates than in the previous margin (up to 25.6% bandwidth reserved for ES). Owing to the consequences exposed, we consider that, as far as Gold subscribers' QoS is downgraded, the network should offer the possibility of a higher rate of Gold sessions in comparison with the rates of other categories (except, obviously, for ES, which are assigned a fixed bandwidth).

Category	BW reserved	bps	Subscribers supported	% of category
ES, 1	40.00%	640000	125,000	6.25%
Gold, 2	18.00%	320000	112,500	37.50%
Silver, 3	37.50%	320000	234,375	33.48%
Bronze, 4	4.50%	32000	281,250	28.13%
TOTAL	100.00%		753,125	**37.66%**

Table 4.23: 40% bandwidth for ES, QCI 2 for Gold subscribers

Table 4.23 (above) indicates the distribution selected for the new threshold and reflects, as well, the aforementioned effects in the bandwidth and occupancies of the various categories. On top of that, reserving 14.4% more bandwidth for ES and downgrading QoS to acceptable parameters for Gold users, we have achieved a higher global occupancy.

4.4.3 High rate of emergency sessions

In this section, we consider that the request for ES surpasses the previous established threshold and keeps increasing until the maximum permitted by the network is reached, e.g. the situation in the scenario regarding the ES' demand is critical. We study the possibility of giving a certain margin of bandwidth for Bronze users and its viability, although at this point this is certainly not a priority. At his stage, the QCI given to Gold sessions is invariably QCI 2.

The first bandwidth assignment defined (after exceeding the 40% established in section 4.4.2) is 60%. Looking back at Table 4.19, in section 4.3.3.3, we can observe the number of sessions expected with approximately 60% of bandwidth applied to ES and 30% occupancy. In order to optimize the network's performance under the current circumstances, the proposed distribution in Table 4.24 (below) approximates to the number of sessions expected with the distribution of Table 4.19, with the limitation that in the later case the total bandwidth required was 113.28%, which, obviously, is not possible to achieve.

Category	BW reserved	bps	Subscribers supported	% of category
ES, 1	60.00%	640000	187,500	9.38%
Gold, 2	13.70%	320000	85,625	28.54%
Silver, 3	23.50%	320000	146,875	20.98%
Bronze, 4	2.80%	32000	175,000	17.50%
TOTAL	100.00%		595,000	**29.75%**

Table 4.24: 60% bandwidth for ES, QCI 2 for Gold subscribers

Comparing the column "subscribers supported" from Table 4.24 with the one in the second half of Table 4.19, we can conclude that the amount of subscribers that the network is capable of supporting in each category, perfectly adapts to the average traffic expected under the present circumstances. Even though supplying service to Bronze users is not a priority anymore, we must say that up to this point we are able to satisfy their expected necessities in terms of bandwidth (we can check in Table 4.24 that Bronze users get 2.8% of bandwidth reserved and that the bandwidth required in Table 4.19 was between 2.43% and 2.88% depending on the percentage of emergency sessions).

The last step is to assign the bandwidth to the various categories reserving 80% for emergency sessions. In this situation, we meet the worst circumstances of the scenario described in previous sections. With the aforementioned reservation for ES the network can support forth a million sessions, we consider that at this stage Bronze sessions' are automatically dropped, Gold users become QCI 2 and Silver users who establish a session get a downgraded QoS (QCI 4, Best Effort). The reasons for this treatment of the QoS parameters are to ensure that emergency sessions are properly handled and to provide service to Gold and Silver subscribers to a reasonable extent.

Category	BW reserved	bps	Subscribers supported	% of category
ES, 1	80.00%	640000	250,000	12.50%

Gold, 2	16.30%	320000	101,875	33.96%
Silver, 4	3.70%	32000	231,250	33.04%
Bronze, -	0.00%	-	-	-
TOTAL	100.00%		583,125	**29.16%**

Table 4.25: 80% bandwidth for ES, QCI 2 for Gold subscribers and 4 for Silver

Table 4.25 (above) exposes the results of enforcing the actions considered necessary in this case (discussed in the last paragraph). It is remarkable that, despite dropping Bronze users and downgrading Silver sessions, the network is capable of supporting almost 30% of the subscribers within the actual conditions. Moreover, Gold users get a significant improvement in the number of sessions supported, maintaining the QCI assigned since the 40% bandwidth reservation for ES. Downgrading QoS for Silver sessions has the effect of making the network able to support approximately a third part of the total number of subscribers, although these accounts suffer, in this case, a considerable change in the quality of their sessions.

It is important to remind that this stage is most unlikely and would seldom take place Therefore, the decisions might seem very drastic, but when the scenario reaches this point, the situation requires such measures.

4.4.4 Performance comparison among the established margins

Finally, in this section we will compare the bandwidths assigned and the subscribers supported within each defined margin through two charts. In the first chart, we can observe the evolution of the bandwidths assigned and, in the second one, the subscribers supported.

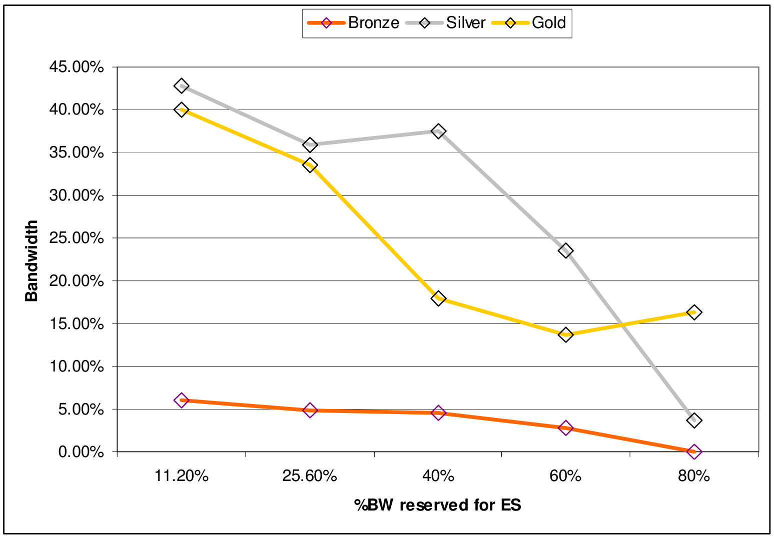

Chart 4.4: Assigned bandwidth

Chart 4.4 (above) shows how the bandwidth is smoothly reduced for Bronze subscribers along the established margins; of course, this is due to the low bandwidth per session needed (compared to the other categories). In the last step, we can see that the bandwidth assigned is null as we defined in section 4.4.3.

Gold and Silver's reserved bandwidths present a particular behavior at two specific points: The first one, at 40% bandwidth reserved for ES, is due to the change in Gold sessions' QCI; which allows the network to assign much more bandwidth to Silver subscribers than to Gold ones, as explained in section 4.4.2 (respecting the established requirement of not penalizing Gold upon Silver accounts). The second one, at 80% bandwidth reserved for ES, is due to the change in Silver sessions' QCI, permitting to increase the bandwidth assigned for Gold sessions (as the chart clearly reflects) and dramatically reducing the necessary bandwidth to maintain the expected Silver sessions.

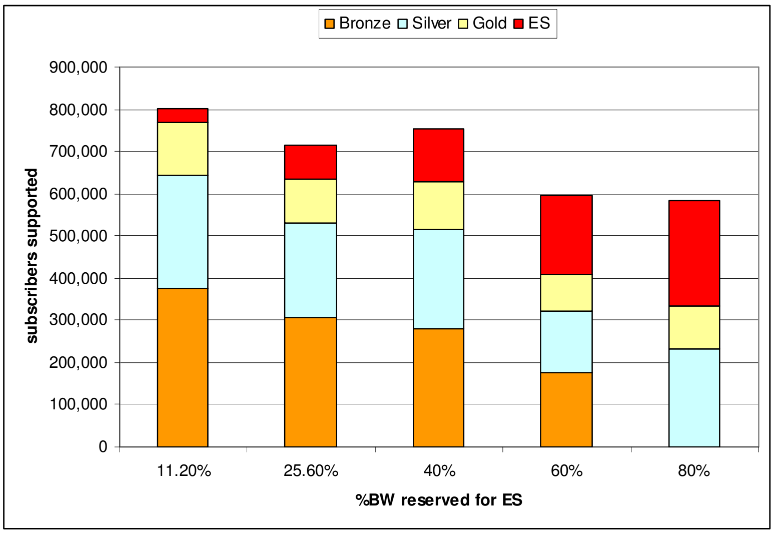

Chart 4.5: Subscribers supported

Chart 4.5 (above) shows the subscribers supported for each category within each established margin. The first noticeable characteristic is that at 40% the subscribers supported increase instead of decreasing. As we have already seen, this is due to the QoS downgrade for Gold sessions at this point.

Regarding the various categories, we can observe that emergency sessions increase consistently, in contrast with Bronze sessions, which have the opposite behavior. The number of Gold sessions allowed remains relatively stable and only decreases significantly when 60% of the bandwidth is reserved for ES (Bronze sessions are not yet automatically dropped and Silver subscribers' QoS has not been downgraded). Similarly to Gold sessions, Silver ones suffer a considerable decrease at 60% bandwidth reserved for ES, but increase in approximately the same proportion at 80%, in expense of the change of QCI from three to four (AF to BE).

Finally, comparing Chart 4.4 and Chart 4.5, we can appreciate the contrast in the proportion of subscribers supported by a certain bandwidth's amount, depending on the QCI assigned. To illustrate this feature, please note the Bronze subscribers supported and the bandwidth assigned to them at each stage, and compare the same features with the ones employed by ES' sessions: The relation bandwidth/user is astonishingly different depending on the QCI selected.

4.5 Call Admission Algorithm

Admission control can ensure high-quality communication by ensuring the availability of bandwidth to carry a load. Inelastic real-time flows such as Voice over Internet Protocol (VoIP) or video conferencing services can benefit from use of an admission control mechanism, as generally the telephony service is configured with over-subscription, meaning that some users may not be able to make a call during peak periods. In the present thesis, the call admission algorithm is a basic part of the architecture, not only because of the aforementioned reason, but also for ensuring the maximum quality for emergency sessions as well as permitting the maximum number of non-emergency sessions defined in the previous section. Therefore, in order to limit the bandwidth per category depending on the current circumstances; the sessions must be accepted or rejected through a Call Admission Algorithm.

In the first place, when a new session arrives, the IMS architecture checks what category of subscription the user has through the Subscription Profile Repository (SPR). Then the algorithm will check at which emergency stage of the scenario the Network is. Presumably, most of the time, the system should be under 11.2% of bandwidth dedicated to ES and, under exceptional circumstances, such as the ones introduced in the current scenario, this rate shall increase over the aforementioned percentage.

In the second place, we calculate the bandwidth permitted at each point. Through the PCEF we can know the number of on-going sessions per category of subscriber, therefore it becomes quite simple to establish upper limits: considering $\boldsymbol{\varphi}$ the number of sessions permitted and $\boldsymbol{\gamma_i}$ the maximum bandwidth per category in Kbps per session (where sub-index **i** = [E, G, S, B] indicates the category), we can establish the upper limit as:

$$\mathbf{UL_{ES,\,i}\;[MB] = (\varphi \cdot \gamma_{i)}\;/\;8{,}000}$$

The φ's (number of sessions) considered are the ones defined in Table 4.20, Table 4.21, Table 4.23, Table 4.24 and Table 4.25. Although the feature that we control through the PCEF is the number of sessions per category, we establish the Upper Limits in MB because in this manner we can easily change the way to control the thresholds (increasing the precision of the system) without any further calculations, in case that we become able to acknowledge the exact bandwidth used by each category through the PCEF in the near future.

In Table 4.26 (below), we present all the data required for the calculation of the Upper Limits within each ES rate's margin. The thresholds that trigger the next bandwidth reservation stages are the upper limits in the *ES rate* column, i.e. 11.2%, 25.6%, 40% and 60% (reserving 25.6%, 40%, 60% and 80% bandwidth for emergency sessions respectively). Please note that within each margin, the total amount of bandwidth distributed among the different categories always add up to twenty-five gigabytes.

ES Rate	i = Category	QCI	φ (sessions)	γ_i (Kbps/session)	$UL_{ESR,\,i}$
ESR ≤ 11.2%	ES	1	35,000	640	**2,800**

	Gold	1	125,000	640	**10,000**
	Silver	3	267,500	320	**10,700**
	Bronze	4	375,000	32	**1,500**
11.2% < ESR ≤ 25.6%	ES	1	80,000	640	**6,400**
	Gold	1	105,000	640	**8,400**
	Silver	3	224,375	320	**8,975**
	Bronze	4	306,250	32	**1,225**
25.6% < ESR ≤ 40%	ES	1	125,000	640	**10,000**
	Gold	2	112,500	320	**4,500**
	Silver	3	234,375	320	**9,375**
	Bronze	4	281,250	32	**1,125**
40% < ESR ≤ 60%	ES	1	187,500	640	**15,000**
	Gold	2	85,625	320	**3,425**
	Silver	3	146,875	320	**5,875**
	Bronze	4	175,000	32	**700**
60% < ESR ≤ 80%	ES	1	250,000	640	**20,000**
	Gold	2	101,875	320	**4,075**
	Silver	4	231,250	32	**925**
	Bronze	-	0	-	-

Table 4.26: Upper Limits for the Call Acceptance Algorithm

The algorithm's structure is shown in Figure 4.1 (below). Please note that after checking the session's category (Emergency, Gold, Silver or Bronze), there is an UL check for each of them (not directly represented in the figure in order to simplify the structure, but schematized by the different branches coming out from each *check category* box). The result of the algorithm is that the system will only accept a new session if its load is placed within the acceptable parameters defined for each margin.

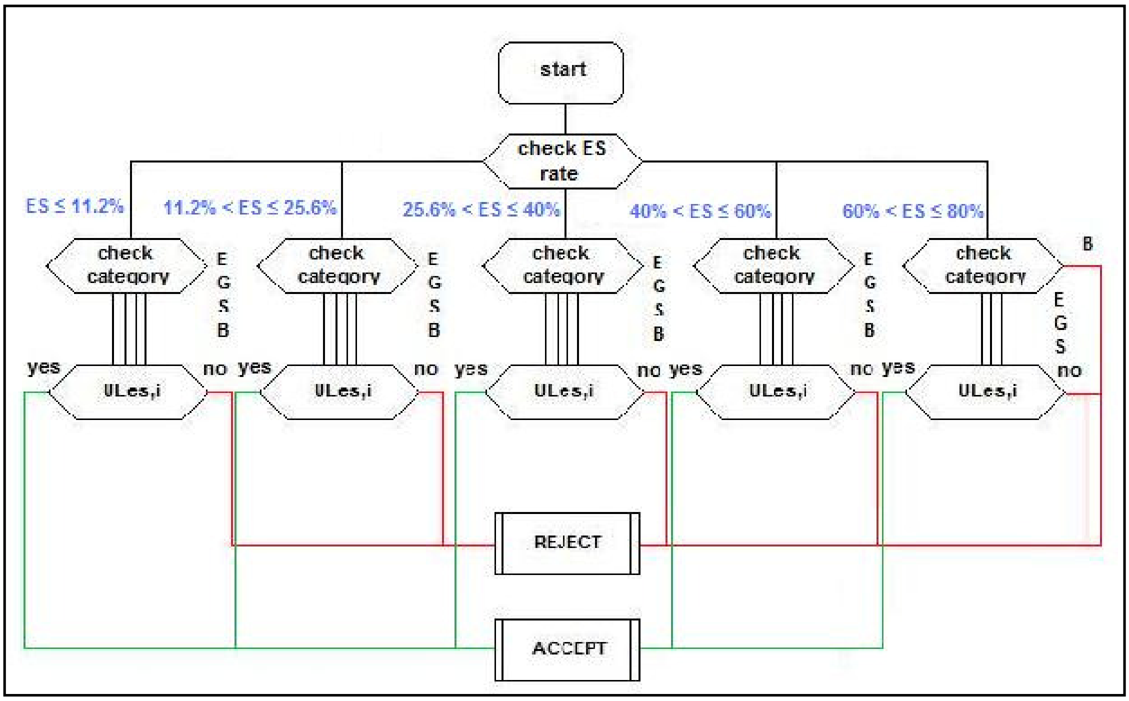

Figure 4.1: Call Admission Algorithm

4.6 Scalability of the model

Departing from the thresholds and bandwidth distributions of the basic model defined after the analysis of the scenario, we propose within this section the mathematical means necessary to escalate the model in order to allow operators to implement the results of the present thesis. In the first place, we will define certain variables that later on will establish the qualitative and quantitative relationships among the different elements involved. The study of the scalability will be divided into two main sections, depending on which variable varies. In chapter 5 – Validation, – we will set up different scenarios to check how the scalable model adapts to different theoretical operators with diverse bandwidths and number of subscribers.

4.6.1 Definition of variables

The basic variables that we consider for the definition of the scalable model are:

- α: non-dimensional variable proportional to [BW / S]: [bandwidth/subscribers]; with α= 1 for BW = 25 GB, S = $2 \cdot 10^6$ subscribers
- τ_i with i = [1, 2, 3, 4]. The different thresholds defined in section 4.4, with the following values:
  - τ_1 = 11.2%
  - τ_2 = 25.6%
  - τ_3 = 40.0%
  - τ_4 = 60.0%
- ß = <restrictions> = [$ß_G$, $ß_S$, $ß_B$, $ß_{S2}$]; where:
  - $ß_G$ = Gold sessions change QoS from qci 1 to qci 2
  - $ß_S$ = Silver sessions change QoS from qci 3 to qci 4
  - $ß_B$ = Bronze sessions are aborted and rejected
  - $ß_{S2}$ = Silver sessions are aborted and rejected
- γ = <bandwidth redistribution parameter> = [γ_G, γ_S, γ_B]:
  - When the distribution of subscribers changes, then "γ" equilibrates the redistribution of bandwidth within the margins limited by the thresholds
  - γ is proportional to [bandwidth/session]. Therefore:
    - γ_G is proportional to [bandwidth/gold session]
    - γ_S is proportional to [bandwidth/silver session]
    - γ_B is proportional to [bandwidth/bronze session]

4.6.2 Variation of α

When the relationship between the available bandwidth and number of subscribers of the operator (α) varies, the restrictions defined in the previous section (ß) are applied earlier or later (triggered by the thresholds τ_i) depending on the result of the non-dimensional variable α. As we have previously established, $\alpha = 1$ for the characteristics of the operator in the scenario, i.e. 25 GB bandwidth and two million subscribers. Therefore, we present two tables with the restrictions applied – after each threshold – for each value of interest in $\alpha = [0.6:1.4]$ that introduces a change in the restrictions. In the first table (Table 4.27) we can see the values for $\alpha > 1$ – which means that there is more bandwidth available (proportionally to the number of subscribers) than in the scenario's model. Therefore, restrictions are lowered. – In the second table (Table 4.28) the values for $\alpha < 1$ – which means that there is less bandwidth available (proportionally to the number of subscribers) than in the scenario's model. Therefore, restrictions are raised earlier. –

	α = 1.00	**α = 1.05**	**α = 1.10**	**α ≥ 1.15**
τ_1	-	-	-	-
τ_2	$ß_G$	-	-	-
τ_3	-	$ß_G$	-	-
τ_4	$ß_S$, $ß_B$	$ß_S$, $ß_B$	$ß_G$, $ß_S$, $ß_B$	$ß_S$, $ß_B$

Table 4.27: $\alpha \geq 1$

For the second table, it is important to remark that when $ß_B$ applies before τ_4, the bandwidth previously reserved for Bronze subscribers is now applied to Gold subscribers. When $ß_{S2}$ applies, bandwidth previously reserved for Silver subscribers is now applied to Gold subscribers as well (it is logical, as this would turn into the only non-emergency category left, because $ß_{S2}$ is always applied after $ß_B$).

	α = 0.60	**α = 0.70**	**α = 0.80**	**α = 1.00**
τ_1	$ß_G$	$ß_G$	$ß_G$	-
τ_2	-	-	-	$ß_G$
τ_3	$ß_B$	$ß_B$	-	-
τ_4	$ß_{S2}$	$ß_S$	$ß_S$, $ß_B$	$ß_S$, $ß_B$

Table 4.28: $\alpha \leq 1$

4.6.3 Variation of γ

For the basic model, we departed in the scenario from the following distribution of the operator's subscribers (considering the distribution of the total number of subscribers, i.e. 100%):

- Gold: 15%
- Silver: 35%
- Bronze: 50%

However, this distribution is likely to vary from one telecommunications operator to another. Moreover, it will vary for a single operator along the time. Therefore, we need a correcting parameter that allows adapting the basic model to the operator's specifications. This correcting parameter is γ, which determines the redistribution of bandwidth in each margin (delimited by the defined thresholds) according to the specific distribution of subscribers of the operator.

In a first approximation to the problem, it is logical to assume that γ must be proportional to the Kbps used per session by each subscription's category. Therefore, for Gold subscribers, γ_G will be proportional to 640 Kbps, for Silver subscribers γ_S will be proportional to 320 Kbps and for Bronze subscribers γ_B will be proportional to 32 Kbps. When QoS downgrades apply by changing QCIs, Gold subscribers will have a $\gamma_{G'}$ proportional to 320 Kbps and Silver ones a $\gamma_{S'}$ proportional to 32 Kbps. This first approach allows establishing a first group of relationships among the different gammas:

- γ_G = $2 \cdot \gamma_S$
- γ_S and $\gamma_{G'}$ = $10 \cdot \gamma_B$
- γ_G and $\gamma_{S'}$ = $20 \cdot \gamma_B$

We also assume that the variations in the distribution of subscribers will be compressed within the following limits:

- Gold subscribers = [5%, 15%]
- Silver subscribers = [25%, 40%]
- Bronze subscribers = [45%, 70%]

The reason that we consider for these limitations within each category is that the prices that operators offer to the general public influence their decision about what service to contract. Therefore, few people (relative to the total number of subscribers) are interested in paying high fees for the services related to Gold accounts.

The process of redistributing the bandwidth consists of various steps and for each step there are various equations to take into account. Before introducing the equations, there are certain variables that need to be defined:

- S_i = <Subscribers of the *i* category in the model> with i = [G, S, B]
- S_i' = <Subscribers of the *i* category in the new system> with i = [G, S, B]
- $\Delta S_i = S_i - S_i'$ = <Variation of subscribers of the *i* category from the model to the new system> with i = [G, S, B]
- BW_i = <bandwidth originally assigned for the *i* category> with i = [G, S, B]
- BW_i' = <first bandwidth re-assignment for the *i* category> with i = [G, S, B]
- BW_i'' = <final bandwidth assigned for the *i* category> with i = [G, S, B]
- Y = <percentage parameter>
- Ω = <bandwidth freed>
- Ω_i = <part of Ω assigned to the *i* category in the first bandwidth distribution>

- Ω' = <bandwidth remaining after first distribution>

The following steps are the description of the proceeding to redistribute the bandwidth and the formulas to apply. This procedure must be applied to all the margins limited by the thresholds:

1. If a ΔS_k increases, at least another one must decrease. If two different $\Delta S_{j,k}$ increase, only one can decrease:
   a. If only one ΔS_i decreases:
      i. $\Omega = Y \cdot BW_i$ where $Y = 1 - \frac{Si'}{Si}$
   b. If ΔS_i and ΔS_j with $i \neq j$ decrease:
      i. $\Omega = Y_i \cdot BW_i + Y_j \cdot BW_j$ where $Yi,j = 1 - \frac{Si.j'}{Si,j}$

2. For those categories where ΔS_i has decreased:
   a. $BW_i' = BW_i \cdot [1 - Y_i]$

3. For those categories where ΔS_i has increased:
   a. If only one category's ΔS_j decreased, for the other two we have:
      i. $BW_i' = BW_i + \frac{\gamma i}{\gamma j} \cdot |\frac{\Delta Si}{\Delta Sj}| \cdot \Omega = BW_i + \Omega_i$ with $i \neq j$ and j referring to the category whose ΔS_j has increased
      ii. $BW_k' = BW_k + \frac{\gamma k}{\gamma j} \cdot |\frac{\Delta Sk}{\Delta Sj}| \cdot \Omega = BW_k + \Omega_k$ with $i \neq j$ and j referring to the category whose ΔS_j has increased
   b. If two categories' $\Delta S_{j,k}$ decrease, for the other one we have:
      i. $BW_i' = BW_i + \frac{\gamma i}{\gamma j} \cdot |\frac{\Delta Si}{\Delta Sj}| \cdot Y_j \cdot BW_j + \frac{\gamma k}{\gamma j} \cdot |\frac{\Delta Sk}{\Delta Sj}| \cdot Y_k \cdot BW_k = BW_i + \Omega_i$ with $i \neq j \neq k$ and j, k referring to the categories whose ΔS_{jk} has increased

4. After the first re-distribution of bandwidth, the remaining bandwidth (Ω') will be greater or equal to zero. Therefore, we will have:
   a. $\Omega' = \Omega - (\Omega_i + \Omega_k) \geq 0$ where $\Omega_k = 0$ if 3.b applies instead of 3.a
   b. If $\Omega' > 0$ then the part corresponding to each category will be distributed through:
      i. For Gold: $\Omega_G' = \gamma_G \cdot \frac{\Omega'}{\gamma G + \gamma S + \gamma B}$
      ii. For Silver: $\Omega_S' = \gamma_S \cdot \frac{\Omega'}{\gamma G + \gamma S + \gamma B}$
      iii. For Bronze: $\Omega_B' = \gamma_B \cdot \frac{\Omega'}{\gamma G + \gamma S + \gamma B}$

5. The final redistribution of bandwidth will be:

   a. If $\Omega' = 0$: $BW_i'' = BW_i'$
   b. If $\Omega' > 0$: $BW_i'' = BW_i' + \Omega_i'$

4.6.4 Methodology to escalate the model

The methodology to apply when escalating the model for a new operator is described in the following steps:

1. If the distribution of subscribers is equal to the initial model and α changes:
   a. If α ↑(α > 1) it means that there is more bandwidth available (proportionally to the number of subscribers): restrictions are lowered according to section 4.6.2
   b. If α ↓(α < 1) it means that there is less bandwidth available (proportionally to the number of subscribers): restrictions are raised earlier according to section 4.6.2
2. If the distribution of subscriber changes and α is equal to the initial model (α = 1):
   a. Those categories that vary are applied their correspondent γ to recalculate the redistribution of bandwidth among categories
3. If both distribution of subscribers and α change:
   a. First step: Those categories that vary are applied their correspondent γ to recalculate the redistribution of bandwidth among categories
   b. Second step: The model calculated for the variation of α (variation of restrictions) is applied to the new distribution

4.7 PCRF policies

In order to carry out the model for Emergency Services, the appropriate policies have to be stored in the PCRF. Policies are stored in Extensible Markup Language (XML) format and enforced by the PCEF. The concept of QoS class identifier and the associated bit rates specify the QoS information for service data flows and bearers on the Gx reference point [6] (between the PCRF and the PCEF). In this section, we will define as well the events that trigger the correspondent actions to be taken – an *event trigger* is a rule specifying the event behavior of the PCEF. The event trigger criteria are supplied to the PCEF by the PCRF function –. The following interactions are to be specified into policies:

- Establish the maximum bandwidth depending on the QCI
- Downgrading the QCI of an IP-CAN bearer depending on an specific threshold
- Upgrading the QCI of an IP-CAN bearer depending on an specific threshold

- Rejecting sessions with a certain QCI
- Aborting sessions with a certain QCI

Event triggers determine when the Event Trigger Function (located in the PCEF) shall signal to the PCRF that an IP-CAN bearer has been modified. An IP-CAN bearer is an IP transmission path of defined capacity, delay and bit error rate for the defined bearer. Bearer binding is the association of the PCC rule to an IP-CAN bearer within that IP-CAN session – the Bearer Binding Function is located in the PCEF –.

The enforcement of the authorized QoS of the IP-CAN bearer can lead to a downgrading or upgrading of the requested bearer QoS by the PCEF as part of a UE-initiated IP-CAN bearer establishment or modification.

4.7.1 High-level policies

We start from the assumption that when an incoming session arrives, the architecture differentiates between emergency and non-emergency sessions by checking the SIP header for emergency indication, as well as being able to provide the information about the user's type of subscription checking the Subscription Profile Repository. Therefore, at the beginning of the algorithm we know the kind of incoming session, i.e. Emergency, Gold, Silver or Bronze.

We keep as well the total bandwidth's percentage required by emergency sessions, dividing them into the following categories (where the percentages represent the thresholds):

- ESR (Emergency Session's Rate) 1: Emergency sessions require less than 11.2% bandwidth
- ESR2: Emergency sessions require between 11.2% and 25.6% bandwidth
- ESR3: Emergency sessions require between 25.6 % and 40% bandwidth
- ESR4: Emergency sessions require between 40% and 60% bandwidth
- ESR5: Emergency sessions require between 60% and 80% bandwidth

Eighty per cent is the maximum bandwidth that we allow for emergency sessions within the total resources. If the state changes from ESR_X to ESR_Y, we must trigger an event in order to make the PCRF acknowledge the situation and make it able to take the appropriate actions.

For the more, we need to maintain the information about the bandwidth used by each category apart from ES. Hence, the following parameters are considered (these parameters can be either in number of sessions or bandwidth, since the variable UL has been considered in both terms, although bandwidth allows much more accurate results):

- ER: "number of on-going sessions" or "bandwidth" employed by emergency sessions

- GR: “number of on-going sessions” or ”bandwidth“ employed by Gold subscribers
- SR: “number of on-going sessions” or ”bandwidth“ employed by Silver subscribers
- BR: “number of on-going sessions” or ”bandwidth“ employed by Bronze subscribers

4.7.1.1 General policy concept for incoming-sessions

Summarizing there must be three conditions evaluated to TRUE in order to accept a session. The general concept would be as described below:

Rule

Conditions:
    If ESR_X   //where X = [1, 2, 3, 4, 5]
    If category Y   //where Y = [E, G, S, B]
    If $Z < UL_{ESR\_X, Y}$ //where Z = [ER, GR, SR, BR]
Actions:
    Accept session, assign QCI   //otherwise we would reject the session

In order to adapt and simplify this concept, we have the possibility to gather the rules in rulesets. Hence, a possible mapping would be as described below:

Ruleset_A

```
Rule_1
        Conditions:
                If ESR1
        Actions:
                Check ruleset_1
Rule_2
        Conditions:
                If ESR2
        Actions:
                Check ruleset_2
Rule_3
        Conditions:
                If ESR3
        Actions:
                Check ruleset_3
Rule_4
        Conditions:
                If ESR4
        Actions:
```

Check ruleset_4
Rule_5
Conditions:
If ESR5
Actions:
Check ruleset_5

Ruleset_X //where X = [1, 2, 3, 4, 5]

Rule_X.E
Conditions:
If category == E
Actions:
Check ruleset_X.E
Rule_X.G
Conditions:
If category == G
Actions:
Check ruleset_X.G
Rule_X.S
Conditions:
If category == S
Actions:
Check ruleset_X.S
Rule_X.B
Conditions:
If category == B
Actions:
Check ruleset_X.B

Ruleset X.Y //where Y = [E, G, S, B]

Rule_X.Y
Conditions:
If $Z < UL_{ESR\_X,\ Y}$ //where Z = [ER, GR, SR, BR]
Actions:
Accept & assign QCI //otherwise REJECT

This way we would have a ruleset that leads to another five possible rulesets that, at the same time, lead to another twenty rulesets (four per ruleset). Therefore, with this structure, we would need to define twenty-six rulesets, but we would only need to check three per incoming session (in the order indicated by the parenthesis):

(1) Ruleset_A:

(2) Ruleset_1:
- (3) Ruleset_1.E
- (3) Ruleset_1.G
- (3) Ruleset_1.S
- (3) Ruleset_1.B

(2) Ruleset_2:
- (3) Ruleset_2.E
- (3) Ruleset_2.G
- (3) Ruleset_2.S
- (3) Ruleset_2.B

(2) Ruleset_3:
- (3) Ruleset_3.E
- (3) Ruleset_3.G
- (3) Ruleset_3.S
- (3) Ruleset_3.B

(2) Ruleset_4:
- (3) Ruleset_4.E
- (3) Ruleset_4.G
- (3) Ruleset_4.S
- (3) Ruleset_4.B

(2) Ruleset_5:
- (3) Ruleset_5.E
- (3) Ruleset_5.G
- (3) Ruleset_5.S
- (3) Ruleset_5.B

4.7.1.2 General policy concept for ongoing-sessions

On-going sessions might have to change their QCI or even be dropped if the situation requires this effect (e.g. the next threshold is reached and the bandwidth reserved for a specific category decreases, so the total number of on-going sessions might exceed the new total bandwidth available for this category).

Rule

Conditions:

If EVENT: ESR from X to Y //where X, Y = [1, 2, 3, 4, 5]

If category Y //where Y = [E, G, S, B]

Actions:

Abort session or change QCI (downgrade or upgrade)

Within this category of rules, we find two different concepts: the abortion of sessions and the QoS change. In order to study what kind of rules we need in more detail, first we need to define the events that will trigger some action. The possible events defined by the thresholds are the following:

- Change from ESR1 to ESR2
- Change from ESR2 to ESR3
- Change from ESR3 to ESR4
- Change from ESR4 to ESR5
- Change from ESR5 to ESR4
- Change from ESR4 to ESR3
- Change from ESR3 to ESR2
- Change from ESR2 to ESR1

As we can see through this classification, there are two kind of events clearly defined, i.e. being ESR_X and ESR_Y, with X, Y = [1, 2, 3, 4, 5] and X > Y, we can change from ESR_X to ESR_Y (implying greater restrictions on bandwidth's use) or vice versa (implying lower restrictions on bandwidth's use). The difference is highly important, because when we have to raise restrictions there might be a number of sessions that need to be dropped, but the other way round this does not happen. Therefore the actions are slightly different in both cases. For this purpose we will classify the events into two categories (although we still have the same eight possible events):

- First category: ESR_12, ESR_23, ESR_34, ESR_45
- Second category: ESR_21, ESR_32, ESR_43, ESR_54

We will begin with the rule concept for the second category as it is much simpler and needs less features. The actions that have to be taken within the second category of events are:

- Upgrade QCI from 2 to 1 for Gold users when ESR_32 is triggered
- Upgrade QCI from 4 to 3 for Silver users when ESR_54 is triggered

Therefore, we will only need two rules for these purposes:

Rule 1

Conditions:

If EVENT ESR_32

If category == G

Actions:

Set QCI 1 (for Gold)

Rule 2

Conditions:

If EVENT ESR_54

If category == S

Actions:

Set QCI 3 (for Silver)

Concerning the first category, we will have to consider the following basic actions:

- Downgrade QCI from 1 to 2 for Gold users when ESR_23 is triggered
- Downgrade QCI from 3 to 4 for Silver users when ESR_45 is triggered
- Drop all Bronze sessions when ESR_45 is triggered

As well as adapting the number of sessions, if necessary, to the new limit “$UL_{ESR\_X,\ Y}$“ (when the number of ongoing sessions surpasses the aforementioned limit). Of course, in the case of emergency sessions this will not happen, as the limit can only increase. Therefore, we will have to consider the following actions:

- Drop “GR - $UL_{ESR\_2,\ G}$” sessions when ESR_12 is triggered
- Drop “SR - $UL_{ESR\_2,\ S}$“ sessions when ESR_12 is triggered
- Drop “BR - $UL_{ESR\_2,\ B}$“ sessions when ESR_12 is triggered
- Drop “GR - $UL_{ESR\_3,\ G}$“ sessions when ESR_23 is triggered
- Drop “SR - $UL_{ESR\_3,\ S}$“ sessions when ESR_23 is triggered
- Drop “BR - $UL_{ESR\_3,\ B}$“ sessions when ESR_23 is triggered
- Drop “GR - $UL_{ESR\_4,\ G}$“ sessions when ESR_34 is triggered
- Drop “SR - $UL_{ESR\_4,\ S}$“ sessions when ESR_34 is triggered
- Drop “BR - $UL_{ESR\_4,\ B}$“ sessions when ESR_34 is triggered
- Drop “GR - $UL_{ESR\_5,\ G}$“ sessions when ESR_45 is triggered
- Drop “SR - $UL_{ESR\_5,\ S}$“ sessions when ESR_45 is triggered

In this case, all the rules will be similar and their structure will be as follows:

Rule

Conditions:

If EVENT ESR_XY //with XY = [12, 23, 34, 45]

If category == Z //with Z = [G, S, B]

Actions:

Abort appropriate number of sessions

(Set QCI 2) //If XY = 23 and Z = G

(Set QCI 4) //If XY = 45 and Z = S

(Abort all sessions) //If XY = 45 and Z = B

A priori, we can condense all rules in a sole ruleset, leading to a ruleset with thirteen rules (eleven for first category and two for the second one). We should also take into consideration different ways of deciding which sessions should be dropped, e.g. the oldest ones.

4.7.2 Implementation of the policies

In this section we present the appropriate tags for the conditions and the actions of the PCC rules evaluated by the PCRF. We also present different examples that contemplate significant cases, based on the high-level definitions of the previous section. Table 4.29 summarizes the conditions to be supported by the PCRF that are of interest for the scope of this thesis.

Condition Tag	Description
<service-identifier>	The application function identifier
<service-class>	The Subscriber Media Profile Identifier
<max-bandwidth>	Maximum bandwidth requested for a particular media
<codec>	Codec identifier for audio and video media sessions
<media-type>	Type of media of the request
<emergency-sessions-rate>	The ESR_X, where X = [1, 2, 3, 4 or 5]
<current-bandwidth>	Which indicates the current bandwidth or number of on-going sessions of E, G, S or B
<event>	Which we will use to indicate the events defined in section 4.6.1.2

Table 4.29: PCC rules' conditions

Please note that the tags <emergency-sessions-rate> and <current-bandwidth> have been added to the already existing ones, in order to achieve the feasibility of the proposed model. Table 4.30 summarizes the actions to be supported by the PCRF that are of interest for the scope of the present thesis. In this case no additional tags have been needed.

Action Tag	Description
<subscribe>	Contains the network level events for which the PCRF requests reports from the gateway
<set>	May include the QCI (<qci>) or the maximum bandwidth (<max-bandwidth>)

	authorized for the session
<abort>	Abort the session
<reject>	Reject the session

Table 4.30: PCC rules' actions

We will exemplify here the PCC rules with five different cases that contemplate the different possibilities presented in the previous section. The first three examples refer to incoming sessions and the other two refer to on-going sessions. In the first case we receive an incoming Gold session – that we will accept as the <current-bandwidth> does not exceed the Upper Limit for Gold sessions in ESR3, which is 4,500 – and we will assign it the appropriate QCI. Let us remind that, when the incoming session arrives, we check Ruleset_A (defined in section 4.6.1.1) and this leads to the ruleset that corresponds to the current ESR. This second ruleset filters the category of the incoming session (we gather the information from the SPR) and we finally check the threshold (together with the rest of conditions) and accept or reject the session. Figure 4.2 shows the aforementioned policy for the gold class.

```
<rule id="ESR3-Gold">
  <conditions>
    <service-class>
      gold
    </service-class>
    <media-type>
      video
    </media-type>
    <codec>
      LQ-video
    </codec>
    <emergency-sessions-rate>
      ESR3
    </emergency-sessions-rate>
    <current-bandwidth>
      3250
    </current-bandwidth>
  </conditions>
  <actions>
    <set>
      <qci>
        2
      </qci>
      <max-bandwidth>
        320
      <max-bandwidth>
    </set>
  </actions>
</rule>
```

Figure 4.2: Accept Gold session rule

The second case shows the rejection of an incoming Bronze session, due to the fact that <current-bandwidth> exceeds the Upper Limit established for the current ESR (which is ESR4 with an Upper Limit for Bronze sessions of 700). Figure 4.3 shows the correspondent policy structure.

```
<rule id=”ESR4-Bronze”>
   <conditions>
      <service-class>
        bronze
      </service-class>
      <media-type>
        audio
      </media-type>
      <codec>
        LQ-audio
      </codec>
      <emergency-sessions-rate>
        ESR4
      </emergency-sessions-rate>
      <current-bandwidth>
        800
      </current-bandwidth>
   </conditions>
   <actions>
      <reject/>
   </actions>
</rule>
```

Figure 4.3: Reject Bronze session rule

In the third case – the last example for incoming sessions – we present a similar situation to the previous one, but this time the <current-bandwidth> does not exceed the current Upper Limit. The particularity in this example is that the user demands high-quality audio (64 Kbps) when bronze users are limited to low-quality audio. Therefore, as shown in Figure 4.4 the rule will accept the session and assign the proper QCI, but re-shaping the maximum bandwidth to 32 Kbps.

```
<rule id=”ESR4-Bronze”>
   <conditions>
      <service-class>
        bronze
      </service-class>
      <media-type>
        audio
      </media-type>
      <codec>
        HQ-audio
```

```
        </codec>
        <emergency-sessions-rate>
         ESR4
        </emergency-sessions-rate>
        <current-bandwidth>
         450
        </current-bandwidth>
    </conditions>
    <actions>
        <set>
            <qci>
             4
            </qci>
            <max-bandwidth>
             32
            <max-bandwidth>
        </set>
        <subscribe>
         QOS_EXCEEDING_AUTHORIZATION
        </subscribe>
    </actions>
</rule>
```

Figure 4.4: Reshape Bronze session rule

The fourth and fifth cases show different possible actions to be taken when some event is triggered. In Figure 4.5 we can see what happens to a Bronze session when the 60% threshold is reached (so the event ESR_45 is triggered), as we change from ESR4 (where Bronze sessions might be accepted) to ESR5 (where no Bronze sessions are accepted and current ones are dropped), the rule takes the action of aborting the session.

```
<rule id="ESR-change-Bronze">
    <conditions>
        <service-class>
         bronze
        </service-class>
        <event>
         ESR_45
        </event >
    </conditions>
    <actions>
        <abort/>
    </actions>
</rule>
```

Figure 4.5: Abort Bronze session rule

In the last case, Figure 4.6 shows what happens to a Silver session when the event ESR_54 is triggered. Mainly, the QCI for Silver sessions improves from ESR5 to ESR4.

```
<rule id=”ESR-change-Silver”>
    <conditions>
        <service-class>
          silver
        </service-class>
        <event>
          ESR_54
        </event >
    </conditions>
    <actions>
        <set>
            <qci>
              3
            </qci>
        </set>
    </actions>
</rule>
```

Figure 4.6: Improve Silver session’s QCI rule

Chapter 5

Validation

This chapter is divided into two main sections. Within the first section, we review the ITU-T recommendations for emergency telecommunications systems and check the compliance of the model presented with the aforementioned recommendations. Within the second section, we present different theoretical operators in order to apply the scalable model designed and validate the adaption of the model presented in this thesis.

5.1 Compliance with the ITU-T Recommendations

This thesis subject has been designed to provide a scalable model for telecommunications operators capable of efficiently supporting emergency and non-emergency sessions under a terrorist attack situation. The International Telecommunication Union has done, and does, extensive research on the field of emergency communications, disaster relief and mitigation operations. The ITU-T (which is mainly in charge of the Emergency Telecommunications System and the Telecommunications for Disaster Relief) aims, through designated specific study groups, to develop recommendations that describe and define a telecommunication capability that facilitates the use of public telecommunication services and systems for communications during emergency operations.

FOKUS is developing the IP Multimedia Subsystem architecture to include the technical specifications and system aspects from 3GPP regarding the elements necessary to support IP Multimedia emergency services within the PEACE project [32]. This thesis complements this goal by adding specific methods for priority access and QoS treatment through local policies that enhance the system's performance.)

Certain requirements defined by the ITU on February 2003, during the workshop on telecommunications for disaster relief that took place in Geneva, include the following aspects that have been the cornerstone of this thesis subject:

- Accessibility
    - Priority access
- Network priority
    - High probability of call completion and adequate QoS
    - QoS for priority communications should scale as network resource become available

The latest list (September 2006) of emergency telecommunications requirements and capabilities, specified in [23], is compiled in Table 5.1, where the particular aspects studied and developed in the model of this thesis are emphasized in italic.

Emergency telecommunications functional requirements and capabilities
Enhanced priority treatment
Secure networks
Location confidentiality
Restorability
Network connectivity
Interoperability
Mobility
Ubiquitous coverage
Survivability/endurability
Real-time transmission to support: voice/real-time text and video/imagery(where bandwidth is available)
Non-real-time transmission to support: messages / non-real-time streams (audio/video)
Scalable bandwidth
Reliability/availability

Table 5.1: Emergency telecommunications functional requirements and capabilities. Source [23]

In order to validate and provide an overview of the contributions of this thesis to the ETS, we will present the main lines of study, recommendations and developments by the ITU-T in the ETS/TDR field according to the features related to this thesis. The standardization activities of the ITU-T on ETS/TDR are divided in the following Study Groups:

- Study Group 2 (to study operational aspects of service provision, networks and performances):
    - E.106 - Description of an international emergency preference scheme (IEPS)
    - E.107 – Description of an ETS and interconnection framework for national implementations of ETS
    - Draft Recommendation E.QSC - Signaling of proposed QoS Service Classes for IP-, ATM- and TDM based multiservice networks
    - Draft Recommendation E.TE - QoS Routing and related traffic engineering methods for IP-, ATM- and TDM-based multiservice networks
- Study Group 3 (to study tariff and accounting principles)
- Study Group 4 (to study telecommunication management):
    - Draft Recommendation M.ets Requirements for Priority Services for critical communications

    - Draft Recommendation M.QoS - QoS management
- Study Group 9 (to study integrated broadband cable networks, television and sound transmission):
    - Supplement to J.160 - Architectural Framework for the delivery of time-critical services over CATV networks using cable modems
    - Draft Recommendation J.et - Emergency Telecommunication
- Study Group 11 (to study signaling requirements and protocols):
    - Amendments to existing Recommendations to support IEPS
    - Draft Recommendation TRQ.IEPS Signaling requirements to support the IEPS and ETS
- Study Group 12 (to study end-to-end transmission performances of networks and terminals):
    - G.107 - Computational model for use in transmission planning
    - G.109 - Definition of categories of speech transmission quality
    - G.1010 - MM QoS/Performance Requirements (G.MMPERF)
    - P.561- In service non-intrusive measurement device (INMD) - Voice service measurements
    - P.562- Analysis and interpretation of INMD voice service measurements
- Study Group 13 (to study multi-protocol and IP-based networks and their interworking):
    - NGN-2004 Project
    - Recommendation Y.1541 - Network performance objectives for IP-based services
    - Recommendation Y.2205 – NGN Emergency telecommunications – Technical considerations
    - Recommendation Y.2171 – Admission control priority levels in NGN
    - Draft Recommendation Y.roec - Network requirements and capabilities to support ETS
- Study Group 15 (to study optical and other transport networks)
- Study Group 16 (to study multimedia services, systems and terminals):
    - Recommendation H.460.4 – Call priority designation for H.323 calls
    - Draft Recommendation F.ETS - System framework, Requirements and System concept
    - Draft Recommendation H.priority - Quality/priority classes
    - Draft Recommendation H.SETS - Security for ETS (H.235)
    - Draft Recommendation F.706 - Description of an International Preference Scheme for Multimedia Services in Support of Disaster Relief Operations and Mitigation
    - Draft Recommendation F.MMCTDR - Description for Multimedia Service Concept to support TDR
- Study Group 17 (to study data networks and telecommunication software):
    - Relevant Recommendations of the X-800 series

From the aforementioned recommendations, the ones that this thesis is related with are E.107, Y.2171 and Y.2205 from SG 2 and 13. The following sections describe the validation of the present thesis within each of these recommendations.

5.1.1 ITU-T Recommendation E.107: ETS and interconnection framework for national implementations of ETS

According to ITU-T the ETS is a national implementation utilizing the features, facilities and applications available in national public networks and service offerings. As such, it could be said to resemble a supplementary service since it can only exist if there is an established telecommunication service. Implementation of ETS by definition is a national matter; however, ETS national implementations are likely to exhibit some of the following characteristics that this thesis subject takes into account and achieves:

- ETS users should be able to use their normal telecommunication terminals to initiate ETS calls or sessions during times of crisis or agreed emergency situations. This requirement is accomplished within the limits established by the thresholds defined.
- An originating national network may use various methods to identify an ETS user requests for ETS telecommunication. The method used in the present model is SIP signaling for emergency communications.
- An ETS call or session is provided end-to-end priority treatment beyond that offered to the general public, which is accomplished in this thesis by assigning priority/QCI 1 to emergency sessions. The priority treatment is applied during the call/session establishment phase, and should continue to be applied for the duration of the call, session or telecommunication. The priority treatment consists of priority mechanisms and features applicable to various aspects (e.g., signaling, control, routing, and media traffic) that are essential for the establishment and continuation of the telecommunication, including:
  - Priority treatment: As services can be expected to traverse multiple network domains, setting admission control priority levels is an important step in the development of the necessary signaling protocol extensions as well as the mechanisms for enabling preferential admission treatment of critical services. Priority treatment mechanisms may include priority call/session set-up (e.g., priority queuing schemes for network resources, Class Based Queuing in the present thesis), access to additional resources (e.g., via alternate routing) and exemption from restrictive network traffic management controls (e.g., call gapping). Pre-emption in the public network (i.e., terminating any established telecommunication to release resources to serve a new ETS call/session request) has been the basis to determine the design of the model, leading to the defined thresholds that allow maximization in the use of the network resources.

5.1.2 ITU-T Recommendation Y.2171: Admission control priority levels in NGNs

According to this Recommendation enhanced priority treatment is an essential requirement for the assured capabilities needed for emergency telecommunications. A critical component of enhanced priority treatment is admission control for telecommunications services seeking entry into a network particularly during emergency conditions when network resources may be depleted. Admission control in the NGN can be enabled by:

- Development of admission control priority levels based on the criticality of services seeking entry in NGNs. This aspect is enabled in the model through the QCI mapping designed, enforcing the advantages in priority treatment (commented in sections 2.5 and 4.1) offered by DS by means of the Differentiated Services Code-Points.
- Development of necessary extensions in signaling protocols that can indicate the desired service priority levels at NGN interfaces. As commented in section 5.1.1, this goal has been achieved by the incorporation of a SIP header in the session initiation signaling.
- Development of admission control mechanisms that can recognize the signaled priority levels and undertake necessary action. The control mechanisms and the consequent actions to be taken are specified in the present thesis through the local policies defined in section 4.6.

Furthermore, the ITU-T emphasizes the fact that NGNs are expected to be truly converged, in the sense that all form of telecommunications services will be (and actually are) handled by these kind of networks: control plane traffic, emergency telecommunications, real-time voice and video services, data services, Virtual Private Network services, traditional best effort traffic, etc. This assumption has been taken into account in this thesis, by considering not only data, best effort traffic and voice services, but also other 3GPP services that require a larger bandwidth such as real-time 3G video-calls. Therefore, in such an environment ITU-T stresses that it is essential to assign priority levels and establish rules for capacity reservation and admission such that critical services are recognized and accepted for session set-up and admission over other services in case of network overloads, these two aspects are present all along the considerations of the design of the model through the scalable scenario presented in the thesis, as capacity reservation and admission considerations have been largely studied along the evolution of the scenario in section 4.3, in order to define the thresholds that characterize the policies and the actions to be taken.

5.1.2.1 Recommendation for admission control priority levels

The ITU-T establishes three admission control priority levels recommended for telecommunications services seeking entry into NGN, but also comments that a network operator may adopt additional priority levels as the choice of priority implementation mechanisms in the transport stratum is up to the network operator. In the present thesis we have considered four different priority levels for the operator to better accomplish the goal of providing the best service to emergency sessions and, in second term, to non-emergency sessions, as well as to achieve a more refined granularity in the policies designed. The three levels recommended by ITU-T are:

- Priority level 1: Traffic with this priority level receives the highest assurance for admission to the network. This level is reserved for emergency telecommunications over NGN. In the present thesis we have assigned this priority level for emergency telecommunications to QCI 1, as recommended.
- Priority level 2: Traffic with this priority level will not receive the same assurance for admission as that given to priority level 1 traffic, but will receive higher assurance for admission than that given to priority level 3 traffic. Examples include real-time services such as VoIP and 3G video-calls. In the present thesis we have improved this recommendation, providing QCI 1 or 2 for Gold users depending on the affordable network resources (e.g., QCI changes from 1 to 2 when emergency sessions employ less than 25.6% of the available bandwidth, as specified in section 4.4.2), with a higher priority over lower QCIs, as well as high bandwidth performance for real-time telecommunications services. In the design of the model QCI 3 has been assigned to Silver users, but in our thesis the characteristics defined for this QCI match better with the "Priority level 2" recommendation rather than level 3.
- Priority level 3: Traffic with this priority level receives the least assurance for admission to the network. Examples include traditional Internet Service Provider (ISP) services (email, web surfing). This recommended priority level matches with the QCI 4 defined in section 4.1.1.3, reserved *a priori* for Bronze accounts.

5.1.3 ITU-T Recommendation Y.2205: NGNs – Emergency telecommunications – Technical considerations

According to this Recommendation, if emergency telecommunications traffic is to be distinguished from normal traffic within the NGN, then appropriate distinguishing labels, also known as markers, are required to be available. Specifically, the Study Group 13 proposes that the SIP resource priority header information (utilized in the control layer to identify priority session) could be mapped to the appropriate DS Code Points (DSCPs) to mark the emergency telecommunications traffic in the IP network layer. Indeed, the methodology followed in the design of our model approaches this proposition of the ITU-T by using the SIP Priority header to mark emergency sessions as described in section 2.4 and distinguish the priority of non-emergency sessions through different tags.

Furthermore, in this Recommendation the ITU-T highlights the following factors as key features in the success of an emergency telecommunication (due to the fact that in a NGN the service and transport stratum are independent):

- Identification and marking of the emergency telecommunication traffic. Accomplished in the present thesis by the means of the SIP header and the DS Code-Points.
- Admission control policy. Accomplished in the present thesis through the policies defined for that purpose.
- Bandwidth allocation policy. Accomplished in the present thesis through the bandwidth thresholds defined.
- Authentication and authorization of emergency telecommunications users. Not included in the design of the present thesis, but implicit in the IMS architecture.

Accordingly to the aforementioned factors, the present thesis gathers these requirements to provide higher rate of success in emergency telecommunications.

In addition to the recommendations in priority treatment exposed in sections 5.1.1 and 5.1.2, in Recommendation Y.2205 the Study Group 13 comments that in case that ordinary services consume the vast majority of finite network resources (as has been studied in our scenario), emergency telecommunications is forced to compete for these same finite resources and can be adversely affected. Therefore, some means of giving priority treatment for emergency services over ordinary telecommunication services should be devised. Primarily, this means:

- Recognizing the authorized emergency telecommunications users.
- Granting the authorized emergency telecommunications users service priority.

In the first case, the IMS architecture “should” take care of the commented feature. In the latest, as we have extensively explained, the model grants the appropriate priority treatment.

5.1.3.1 Admission control considerations for higher probability of admission

Finally, the ITU-T specifies that one of the functions of the resource and admission control function (RACF) is supporting QoS control to include resource admission and resource reservation if desired by the service provider. As such, during times of high service demand from users, some service requests may need to be denied. If these denials do not occur, then the NGN may not fully guarantee service quality in emergency cases. The present thesis takes this aspect into consideration, reserving certain shares for each kind of session (prioritizing emergency sessions over the rest) and dropping low-priority sessions, as well as denying new session petitions depending on the current enforced policies if the resources are scarce.

5.2 Validation of the scalable model

For the validation of the scalable model we introduce three operators with diverse characteristics. In the first operator the α variable diverges from the basic model, but the distribution of subscribers is the same. In the second operator, the characteristic that varies is the distribution of subscribers. Finally, in the third operator both variables are different to those considered in the basic model.

5.2.1 First operator: variation of α

The specifications of the first operator are the following:

- Total Bandwidth: 10 Gbytes
- Number of subscribers: 1 million
- Subscription categories:
  - Gold (15 %): 150,000 subscribers
  - Silver (35 %): 350,000 subscribers
  - Bronze (50 %): 500,000 subscribers

As we can see, the distribution of subscribers has the same structure as the basic model, but the bandwidth available and total number of subscribers differ. The first step is to calculate α, considering BW and S the available bandwidth and number of subscribers in the basic model respectively, and BW', S' the ones in the new operator:

$$\alpha = (BW' / S') / (BW / S) = 0.8$$

In Table 4.28 we can see at what point the QCI restrictions must be applied. In this case β_G applies after the first threshold. The new upper limits for the Call Acceptance Algorithm will be as shown in Table 5.2.

ES Rate	i = Category	QCI	φ (sessions)	γ_i (Kbps/session)	$UL_{ESR, i}$
ESR ≤ 11.2%	ES	1	14,000	640	**1,120**
	Gold	1	50,000	640	**4,000**
	Silver	3	107,000	320	**4,280**
	Bronze	4	150,000	32	**600**
11.2% < ESR ≤ 25.6%	ES	1	32,000	640	**2,560**
	Gold	2	84,000	320	**3,360**
	Silver	3	89,750	320	**3,590**
	Bronze	4	122,500	32	**490**
25.6% < ESR ≤ 40%	ES	1	50,000	640	**4,000**
	Gold	2	45,000	320	**1,800**
	Silver	3	93,750	320	**3,750**
	Bronze	4	112,500	32	**450**
40% < ESR ≤ 60%	ES	1	75,000	640	**6,000**
	Gold	2	34,250	320	**1,370**

	Silver	3	58,750	320	**2,350**
	Bronze	4	70,000	32	**280**
60% < ESR ≤ 80%	ES	1	100,000	640	**8,000**
	Gold	2	40,750	320	**1,630**
	Silver	4	92,500	32	**370**
	Bronze	-	0	-	**-**

Table 5.2: Upper Limits for the CAA in the first operator

And the difference of maximum occupancy within each margin with the basic model is shown in Chart 5.1 (below).

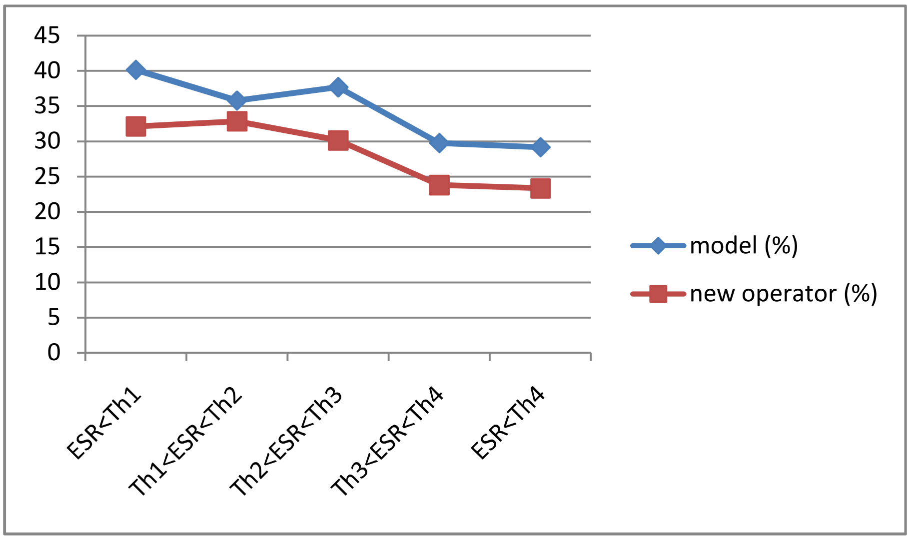

Chart 5.1: Occupancy difference between model and first operator

As we can observe in the chart, the difference in maximum occupancy is 5-8%, except in the second margin (when the change in restrictions apply, i.e. QCI 2 for Gold sessions), where both maximum occupancies become almost equal with a 2.95% difference. The distribution of bandwidth in the new operator is consistent with the basic model (presents the same behavior) and the advance in the restrictions allows certain improvement of this consistency in the second margin. However, the best solution to improve the maximum occupancy within all margins is to invest in more available bandwidth. Anyhow, we have to remind that these occupancies consider that all subscribers establish sessions with the most-expensive service they have contracted (e.g. high-quality video for Gold users). Therefore, as we work with bandwidth reservation (Table 5.2) the occupancies shown in Chart 5.1 are the minimum occupation that the operator would be able to offer. In other words, the real maximum occupations depend on the type of sessions that users establish at a certain moment and these will be always higher than the minimums of the chart.

5.2.2 Second operator: variation of the subscriber's distribution

The specifications of the second operator are the following:

- Total Bandwidth: 25 Gbytes
- Number of subscribers: 2 millions
- Subscription categories:
  - Gold (10 %): 200,000 subscribers
  - Silver (40 %): 800,000 subscribers
  - Bronze (50 %): 1,000,000 subscribers

As we can see, the distribution of subscribers has changed in comparison to the basic model, but the bandwidth available and total number of subscribers has not varied. Therefore, α = 1 as in the reference model. For this second operator we have to follow the steps defined in section 4.6.3, which lead to the results in bandwidth reservation of Table 5.3.

ES Rate	i = Category	QCI	φ (sessions)	γ_i (Kbps/session)	$UL_{ESR,\,i}$
ESR ≤ 11.2%	ES	1	35,000	640	**2,800.00**
	Gold	1	95,430	640	**7,634.41**
	Silver	3	321,263	320	**12,850.54**
	Bronze	4	428,972	32	**1,715.89**
11.2% < ESR ≤ 25.6%	ES	1	80,000	640	**6,400.00**
	Gold	1	80,161	640	**6,412.90**
	Silver	3	269,536	320	**10,781.45**
	Bronze	4	351,413	32	**1,405.65**
25.6% < ESR ≤ 40%	ES	1	125,000	640	**10,000.00**
	Gold	2	85,887	320	**3,435.48**
	Silver	3	258,569	320	**10342,75**
	Bronze	4	305,444	32	**1,221.78**
40% < ESR ≤ 60%	ES	1	187,500	640	**15,000**
	Gold	2	65,369	320	**2,614.78**
	Silver	3	165,289	320	**6,611.55**
	Bronze	4	195,494	32	**781.98**
60% < ESR ≤ 80%	ES	1	250,000	640	**20,000.00**
	Gold	2	95,701	320	**3,828.03**
	Silver	4	292,992	32	**1,171.97**
	Bronze	-	0	-	**-**

Table 5.3: Upper Limits for the CAA in the second operator

And the difference of maximum occupancy within each margin with the basic model is shown in Chart 5.2 (below).

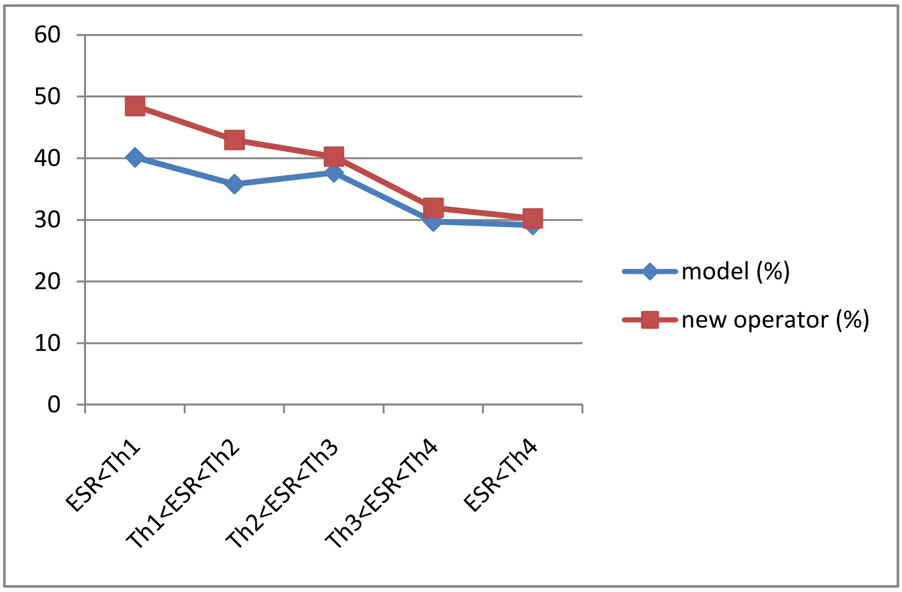

Chart 5.2: Occupancy difference between model and second operator

The chart shows the consistency of the escalated model in the second operator with the reference model, as the behavior of the statistics is clearly similar. In this case we find that the maximum occupancy has improved slightly, this feature is due to the fact that having less Gold subscribers the system can free bandwidth resources to re-distribute among all categories.

5.2.3 Third operator: variation of both variables

For the last operator we will take advantage of the distribution calculated for the second one. On the other hand, the α parameter will be greater than one (opposite case to first operator). The specifications of the third operator are the following:

- Total Bandwidth: 13.75 Gbytes
- Number of subscribers: 1 million
- Subscription categories:
  - Gold (10 %): 100,000 subscribers
  - Silver (40 %): 400,000 subscribers
  - Bronze (50 %): 500,000 subscribers

As we can see, the distribution of subscribers has changed in comparison to the basic model, as well as the bandwidth available and total number of. Therefore, the first step is to calculate α.

$$\alpha = (BW' / S') / (BW / S) = 1.1$$

In the first place and as defined in section 4.6.4, for this second operator we have to follow the steps of section 4.6.3 and then apply the β corrections of section 4.6.2. This process leads to the results in bandwidth reservation of Table 5.4.

ES Rate	i = Category	QCI	φ (sessions)	γ_i (Kbps/session)	$UL_{ESR, i}$
ESR ≤ 11.2%	ES	1	19,250	640	**1,540.00**
	Gold	1	52,487	640	**4,198.92**
	Silver	3	176,695	320	**7,067.79**
	Bronze	4	235,934	32	**943.74**
11.2% < ESR ≤ 25.6%	ES	1	44,000	640	**3,520.00**
	Gold	1	44,089	640	**3,527.10**
	Silver	3	148,245	320	**5,929.80**
	Bronze	4	193,277	32	**773.10**
25.6% < ESR ≤ 40%	ES	1	68,750	640	**5,500.00**
	Gold	1	23,619	640	**1,889.51**
	Silver	3	142,213	320	**5,688.51**
	Bronze	4	167,994	32	**671.98**
40% < ESR ≤ 60%	ES	1	103,125	640	**8,250.00**
	Gold	1	17,977	640	**1,438.13**
	Silver	3	90,909	320	**3,636.35**
	Bronze	4	107,522	32	**430.09**
60% < ESR ≤ 80%	ES	1	137,500	640	**11,000.00**
	Gold	1	26,318	640	**2,105.42**
	Silver	4	161,146	32	**644.58**
	Bronze	-	0	-	**-**

Table 5.4: Upper Limits for the CAA in the third operator

And the difference of maximum occupancy within each margin with the basic model is shown in Chart 5.3 (below).

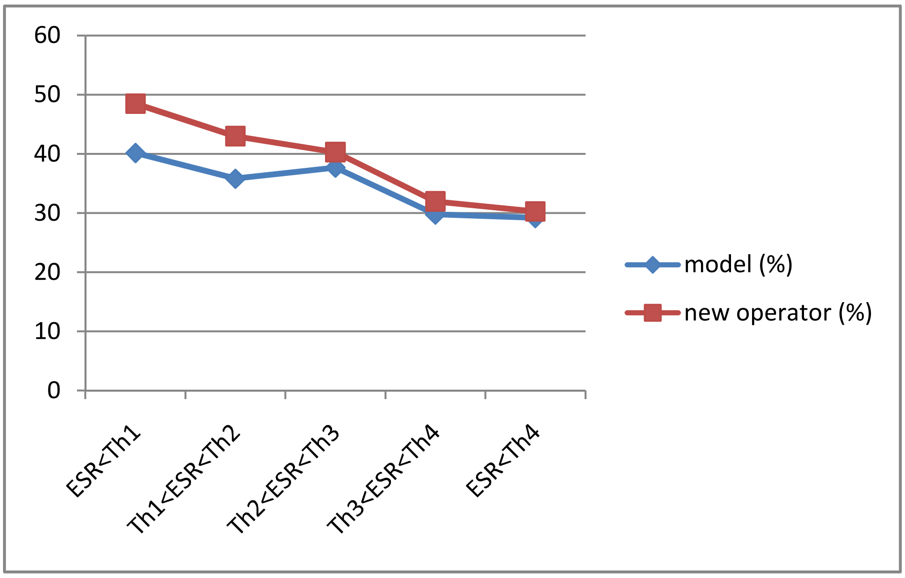

Chart 5.3: Occupancy difference between model and third operator

The chart shows the consistency of the escalated model in the third operator with the reference model, as the behavior of the statistics is clearly similar and converges as the thresholds are triggered. In this case we find that the maximum occupancy has improved slightly at the beginning, this feature is due to the same fact as in the second operator, i.e. by having less Gold subscribers the system can free bandwidth resources to re-distribute among all categories. In the first two margins we can observe as well an improvement in the maximum category comparing Chart 5.2 and Chart 5.3, this is due to the feature $\alpha > 1$ which means that there is more bandwidth available (proportionally to the number of subscribers) in this last operator.

Chapter 6

Summary and outlook

This thesis presented the design of a novel scalable emergency services control model based on existing technologies for the support of emergency services in NGNs and was developed in FOKUS Institute for Telecommunication Technology Research.

The model proposed is a complementary emergency solution for NGNs. Complementary because it takes into account certain aspects that the IMS architecture does not, such as provisioning of preferential treatment not only to emergency communications, but also for non-emergency communications; bandwidth reservation and scalability for operators.

The enhancements are focused not only on the provision of preferential treatment at the beginning and during the sessions, but also on the simplicity of implementation (through the scalability of the model) for operators, i.e. if the operator's characteristics vary the adaption of the model is as simple as recalculating the parameters of the model and apply these changes within the appropriate policies stored in the PCRF. Therefore, the policies format was designed in order to provide a mechanism to easily update and modify policy information.

As it can be seen, the scalable model provides support for emergency services in a controllable and adaptable way for telecommunication operators. Anyhow, within the thesis we have considered that the model is designed for operators which offer three main well-differentiated classes of subscriptions to clients (which we called Gold, Silver and Bronze in the present work) as it is the most common model among operators. Indeed, another approach to this thesis would be to consider that the service offered by operators consists of a different number of classes.

Currently, an optimized mathematical algorithm for best scalability, based on the coefficients applied to the presented model, is under discussion and development at FOKUS.

In conclusion, the presented emergency services control model for the support of emergency services in NGNs is designed to become a great and useful tool for telecommunications' operators due to its scalable features and simplicity of implementation.

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Appendix A

Decrease step error

In section 4.3.2 we assume that the steps of 5% in the increase of ES involve a decrement of 1% for Gold subscribers and a 2% in both Silver and Bronze subscribers. This assumption is considered for simplicity. However, we prove in this section the validity of the assumption by calculating the error margin and proving that it is negligible.

The variables considered in this appendix are:

- ΔES: Emergency on-going sessions' rate variation [percentage]
- ΔG: Gold on-going sessions' rate variation assumed [percentage]
- ΔS: Silver on-going sessions' rate variation assumed [percentage]
- ΔB: Bronze on-going sessions' rate variation assumed [percentage]
- ΔG': Gold on-going sessions' rate linear variation [percentage]
- ΔS': Silver on-going sessions' rate linear variation [percentage]
- ΔB': Bronze on-going sessions' rate linear variation [percentage]
- Θ: Occupancy, as defined in section 4.2.3 [percentage or sessions]
- ε: Error [percentage]
- $\dot{\varepsilon}$: Error [sessions]

The assumption in chapter four implies:

- For each increment of 5% ES (ΔES = 5%):
  - ΔG = - 1.00%
  - ΔS = - 2.00%
  - ΔB = - 2.00%

If a linear assumption had been considered, then the decrements for Gold, Silver and Bronze on-going sessions, implied by the increment ΔES = 5%, would be as presented below:

- For each increment of 5% ES (ΔES = 5%):
  - ΔG' = - 1.05%
  - ΔS' = - 1.85%
  - ΔB' = - 2.10%

Therefore, the percentage error (ε) in each non-emergency category that we approximate by the assumption (for each time that we consider an increment ΔES = 5%) is:

- For Gold sessions:
  - $\varepsilon = |\Delta G - \Delta G'| = 0.05\% = 0.0005$
- For Silver sessions:
  - $\varepsilon = |\Delta S - \Delta S'| = 0.15\% = 0.0015$
- For Bronze sessions:
  - $\varepsilon = |\Delta B - \Delta B'| = 0.10\% = 0.0010$

Finally, we prove that these errors are negligible in terms of sessions and bandwidth through two examples (i.e. two different occupancies):

- Occupancy 20%, i.e. 400,000 subscribers with an established session. Therefore, we have Θ = 20% = 400,000 sessions and ΔES = 5%, so $\Theta \cdot \Delta ES$ = 20,000 sessions.
  - For Gold sessions (maximum 640 Kb per session):
    - $\dot{\varepsilon} = 20{,}000 \cdot 0.0005 = 10$ sessions
    - In bandwidth: 800 KB / 25 GB = 0.0032% of the total BW
  - For Silver sessions (maximum 320 Kb per session):
    - $\dot{\varepsilon} = 20{,}000 \cdot 0.0015 = 30$ sessions
    - In bandwidth: 1200 KB / 25 GB = 0.0048% of the total BW
  - For Bronze sessions (maximum 32 Kb per session):
    - $\dot{\varepsilon} = 20{,}000 \cdot 0.0010 = 20$ sessions
    - In bandwidth: 80 KB / 25 GB = 0.00032% of the total BW
- Occupancy 40%, i.e. 800,000 subscribers with an established session. Therefore, we have Θ = 40% = 800,000 sessions and ΔES = 5%, so $\Theta \cdot \Delta ES$ = 40,000 sessions.
  - For Gold sessions (maximum 640 Kb per session):
    - $\dot{\varepsilon} = 40{,}000 \cdot 0.0005 = 20$ sessions
    - In bandwidth: 1,600 KB / 25 GB = 0.0064% of the total BW
  - For Silver sessions (maximum 320 Kb per session):
    - $\dot{\varepsilon} = 40{,}000 \cdot 0.0015 = 60$ sessions
    - In bandwidth: 2,400 KB / 25 GB = 0.0096% of the total BW
  - For Bronze sessions (maximum 32 Kb per session):
    - $\dot{\varepsilon} = 40{,}000 \cdot 0.0010 = 40$ sessions
    - In bandwidth: 160 KB / 25 GB = 0.00064% of the total BW

Appendix B

Extended Tables

This appendix includes and completes the tables in chapter four. The tables have the same structure as the ones in section 4.3 “Evolution of the scenario and network’s performance”. They are ordered by occupancies.

Occupancy 20 %

Within this section, the QCI’s for the different categories are the initial standards described in section 4.2.2.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	60.000	640	5	19,20%
Gold, 1	18%	72.000	640	6	23,04%
Silver, 3	31%	124.000	320	5	19,84%
Bronze, 4	36%	144.000	32	1	2,30%
TOTAL	100%	400.000		16	64,38%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	80.000	640	6	25,60%
Gold, 1	17%	68.000	640	5	21,76%
Silver, 3	29%	116.000	320	5	18,56%
Bronze, 4	34%	136.000	32	1	2,18%
TOTAL	100%	400.000		17	68,10%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	100.000	640	8	32,00%
Gold, 1	16%	64.000	640	5	20,48%
Silver, 3	27%	108.000	320	4	17,28%
Bronze, 4	32%	128.000	32	1	2,05%
TOTAL	100%	400.000		18	71,81%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	120.000	640	10	38,40%
Gold, 1	15%	60.000	640	5	19,20%
Silver, 3	25%	100.000	320	4	16,00%
Bronze, 4	30%	120.000	32	0	1,92%
TOTAL	100%	400.000		19	75,52%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	140.000	640	11	44,80%
Gold, 1	14%	56.000	640	4	17,92%
Silver, 3	23%	92.000	320	4	14,72%
Bronze, 4	28%	112.000	32	0	1,79%
TOTAL	100%	400.000		20	79,23%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	160.000	640	13	51,20%
Gold, 1	13%	52.000	640	4	16,64%
Silver, 3	21%	84.000	320	3	13,44%
Bronze, 4	26%	104.000	32	0	1,66%
TOTAL	100%	400.000		21	82,94%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	45%	180.000	640	14	57,60%
Gold, 1	12%	48.000	640	4	15,36%
Silver, 3	19%	76.000	320	3	12,16%
Bronze, 4	24%	96.000	32	0	1,54%
TOTAL	100%	400.000		22	86,66%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	50%	200.000	640	16	64,00%
Gold, 1	11%	44.000	640	4	14,08%
Silver, 3	17%	68.000	320	3	10,88%
Bronze, 4	22%	88.000	32	0	1,41%
TOTAL	100%	400.000		23	90,37%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	55%	220.000	640	18	70,40%
Gold, 1	10%	40.000	640	3	12,80%
Silver, 3	15%	60.000	320	2	9,60%
Bronze, 4	20%	80.000	32	0	1,28%
TOTAL	100%	400.000		24	94,08%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	60%	240.000	640	19	76,80%
Gold, 1	9%	36.000	640	3	11,52%
Silver, 3	13%	52.000	320	2	8,32%
Bronze, 4	18%	72.000	32	0	1,15%
TOTAL	100%	400.000		24	97,79%

Category,	Percentage of	Number of	Bandwidth per	Total bandwidth per	% Total BW

QCI	sessions	sessions	session (Kb)	category (GB)	
ES, 1	62,50%	250.000	640	20	80,00%
Gold, 1	8,50%	34.000	640	3	10,88%
Silver, 3	12,00%	48.000	320	2	7,68%
Bronze, 4	17,00%	68.000	32	0	1,09%
TOTAL	100,00%	400.000		25	99,65%

Occupancy 25%

Within this section, the first half of the tables corresponds to Gold: QCI 1 and the second half to Gold: QCI 2, showing what the changes would be in the total bandwidth required by each category.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	25.000	640	2	8,00%
Gold, 1	20%	100.000	640	8	32,00%
Silver, 3	35%	175.000	320	7	28,00%
Bronze, 4	40%	200.000	32	1	3,20%
TOTAL	100%	500.000		18	71,20%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	50.000	640	4	16,00%
Gold, 1	19%	95.000	640	8	30,40%
Silver, 3	33%	165.000	320	7	26,40%
Bronze, 4	38%	190.000	32	1	3,04%
TOTAL	100%	500.000		19	75,84%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	75.000	640	6	24,00%
Gold, 1	18%	90.000	640	7	28,80%
Silver, 3	31%	155.000	320	6	24,80%
Bronze, 4	36%	180.000	32	1	2,88%
TOTAL	100%	500.000		20	80,48%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	100.000	640	8	32,00%
Gold, 1	17%	85.000	640	7	27,20%
Silver, 3	29%	145.000	320	6	23,20%
Bronze, 4	34%	170.000	32	1	2,72%
TOTAL	100%	500.000		21	85,12%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	125.000	640	10	40,00%
Gold, 1	16%	80.000	640	6	25,60%

Silver, 3	27%	135.000	320	5	21,60%
Bronze, 4	32%	160.000	32	1	2,56%
TOTAL	100%	500.000		22	89,76%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	150.000	640	12	48,00%
Gold, 1	15%	75.000	640	6	24,00%
Silver, 3	25%	125.000	320	5	20,00%
Bronze, 4	30%	150.000	32	1	2,40%
TOTAL	100%	500.000		24	94,40%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	175.000	640	14	56,00%
Gold, 1	14%	70.000	640	6	22,40%
Silver, 3	23%	115.000	320	5	18,40%
Bronze, 4	28%	140.000	32	1	2,24%
TOTAL	100%	500.000		25	99,04%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	200.000	640	16	64,00%
Gold, 1	13%	65.000	640	5	20,80%
Silver, 3	21%	105.000	320	4	16,80%
Bronze, 4	26%	130.000	32	1	2,08%
TOTAL	100%	500.000		26	103,68%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	45%	225.000	640	18	72,00%
Gold, 1	12%	60.000	640	5	19,20%
Silver, 3	19%	95.000	320	4	15,20%
Bronze, 4	24%	120.000	32	0	1,92%
TOTAL	100%	500.000		27	108,32%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	50%	250.000	640	20	80,00%
Gold, 1	11%	55.000	640	4	17,60%
Silver, 3	17%	85.000	320	3	13,60%
Bronze, 4	22%	110.000	32	0	1,76%
TOTAL	100%	500.000		28	112,96%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	25.000	640	2	8,00%
Gold, 2	20%	100.000	320	4	16,00%
Silver, 3	35%	175.000	320	7	28,00%

Bronze, 4	40%	200.000	32	1	3,20%
TOTAL	100%	500.000		14	55,20%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	50.000	640	4	16,00%
Gold, 2	19%	95.000	320	4	15,20%
Silver, 3	33%	165.000	320	7	26,40%
Bronze, 4	38%	190.000	32	1	3,04%
TOTAL	100%	500.000		15	60,64%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	75.000	640	6	24,00%
Gold, 2	18%	90.000	320	4	14,40%
Silver, 3	31%	155.000	320	6	24,80%
Bronze, 4	36%	180.000	32	1	2,88%
TOTAL	100%	500.000		17	66,08%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	100.000	640	8	32,00%
Gold, 2	17%	85.000	320	3	13,60%
Silver, 3	29%	145.000	320	6	23,20%
Bronze, 4	34%	170.000	32	1	2,72%
TOTAL	100%	500.000		18	71,52%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	125.000	640	10	40,00%
Gold, 2	16%	80.000	320	3	12,80%
Silver, 3	27%	135.000	320	5	21,60%
Bronze, 4	32%	160.000	32	1	2,56%
TOTAL	100%	500.000		19	76,96%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	150.000	640	12	48,00%
Gold, 2	15%	75.000	320	3	12,00%
Silver, 3	25%	125.000	320	5	20,00%
Bronze, 4	30%	150.000	32	1	2,40%
TOTAL	100%	500.000		21	82,40%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	175.000	640	14	56,00%
Gold, 2	14%	70.000	320	3	11,20%
Silver, 3	23%	115.000	320	5	18,40%

Bronze, 4	28%	140.000	32	1	2,24%
TOTAL	100%	500.000		22	87,84%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	200.000	640	16	64,00%
Gold, 2	13%	65.000	320	3	10,40%
Silver, 3	21%	105.000	320	4	16,80%
Bronze, 4	26%	130.000	32	1	2,08%
TOTAL	100%	500.000		23	93,28%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	45%	225.000	640	18	72,00%
Gold, 2	12%	60.000	320	2	9,60%
Silver, 3	19%	95.000	320	4	15,20%
Bronze, 4	24%	120.000	32	0	1,92%
TOTAL	100%	500.000		25	98,72%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	50%	250.000	640	20	80,00%
Gold, 2	11%	55.000	320	2	8,80%
Silver, 3	17%	85.000	320	3	13,60%
Bronze, 4	22%	110.000	32	0	1,76%
TOTAL	100%	500.000		26	104,16%

Occupancy 30%

Within this section, the first half of the tables corresponds to Gold: QCI 1 and the second half to Gold: QCI 2, showing what the changes would be in the total bandwidth required by each category.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	30.000	640	2	9,60%
Gold, 1	20%	120.000	640	10	38,40%
Silver, 3	35%	210.000	320	8	33,60%
Bronze, 4	40%	240.000	32	1	3,84%
TOTAL	100%	600.000		21	85,44%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	60.000	640	5	19,20%
Gold, 1	19%	114.000	640	9	36,48%
Silver, 3	33%	198.000	320	8	31,68%
Bronze, 4	38%	228.000	32	1	3,65%
TOTAL	100%	600.000		23	91,01%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	90.000	640	7	28,80%
Gold, 1	18%	108.000	640	9	34,56%
Silver, 3	31%	186.000	320	7	29,76%
Bronze, 4	36%	216.000	32	1	3,46%
TOTAL	100%	600.000		24	96,58%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	120.000	640	10	38,40%
Gold, 1	17%	102.000	640	8	32,64%
Silver, 3	29%	174.000	320	7	27,84%
Bronze, 4	34%	204.000	32	1	3,26%
TOTAL	100%	600.000		26	102,14%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	150.000	640	12	48,00%
Gold, 1	16%	96.000	640	8	30,72%
Silver, 3	27%	162.000	320	6	25,92%
Bronze, 4	32%	192.000	32	1	3,07%
TOTAL	100%	600.000		27	107,71%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	180.000	640	14	57,60%
Gold, 1	15%	90.000	640	7	28,80%
Silver, 3	25%	150.000	320	6	24,00%
Bronze, 4	30%	180.000	32	1	2,88%
TOTAL	100%	600.000		28	113,28%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	210.000	640	17	67,20%
Gold, 1	14%	84.000	640	7	26,88%
Silver, 3	23%	138.000	320	6	22,08%
Bronze, 4	28%	168.000	32	1	2,69%
TOTAL	100%	600.000		30	118,85%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	41,67%	250.000	640	20	80,00%
Gold, 1	12,67%	76.000	640	6	24,32%
Silver, 3	20,33%	122.000	320	5	19,52%
Bronze, 4	25,33%	152.000	32	1	2,43%
TOTAL	100,00%	600.000		32	126,27%

Appendix B: Extended Tables

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	30.000	640	2	9,60%
Gold, 2	20%	120.000	320	5	19,20%
Silver, 3	35%	210.000	320	8	33,60%
Bronze, 4	40%	240.000	32	1	3,84%
TOTAL	100%	600.000		17	66,24%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	60.000	640	5	19,20%
Gold, 2	19%	114.000	320	5	18,24%
Silver, 3	33%	198.000	320	8	31,68%
Bronze, 4	38%	228.000	32	1	3,65%
TOTAL	100%	600.000		18	72,77%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	90.000	640	7	28,80%
Gold, 2	18%	108.000	320	4	17,28%
Silver, 3	31%	186.000	320	7	29,76%
Bronze, 4	36%	216.000	32	1	3,46%
TOTAL	100%	600.000		20	79,30%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	120.000	640	10	38,40%
Gold, 2	17%	102.000	320	4	16,32%
Silver, 3	29%	174.000	320	7	27,84%
Bronze, 4	34%	204.000	32	1	3,26%
TOTAL	100%	600.000		21	85,82%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	150.000	640	12	48,00%
Gold, 2	16%	96.000	320	4	15,36%
Silver, 3	27%	162.000	320	6	25,92%
Bronze, 4	32%	192.000	32	1	3,07%
TOTAL	100%	600.000		23	92,35%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	180.000	640	14	57,60%
Gold, 2	15%	90.000	320	4	14,40%
Silver, 3	25%	150.000	320	6	24,00%
Bronze, 4	30%	180.000	32	1	2,88%
TOTAL	100%	600.000		25	98,88%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	210.000	640	17	67,20%
Gold, 2	14%	84.000	320	3	13,44%
Silver, 3	23%	138.000	320	6	22,08%
Bronze, 4	28%	168.000	32	1	2,69%
TOTAL	100%	600.000		26	105,41%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	240.000	640	19	76,80%
Gold, 2	13%	78.000	320	3	12,48%
Silver, 3	21%	126.000	320	5	20,16%
Bronze, 4	26%	156.000	32	1	2,50%
TOTAL	100%	600.000		28	111,94%

Occupancy 35%

Within this section, the first half of the tables corresponds to Gold: QCI 1 and the second half to Gold: QCI 2, showing what the changes would be in the total bandwidth required by each category.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	35.000	640	3	11,20%
Gold, 1	20%	140.000	640	11	44,80%
Silver, 3	35%	245.000	320	10	39,20%
Bronze, 4	40%	280.000	32	1	4,48%
TOTAL	100%	700.000		25	99,68%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	70.000	640	6	22,40%
Gold, 1	19%	133.000	640	11	42,56%
Silver, 3	33%	231.000	320	9	36,96%
Bronze, 4	38%	266.000	32	1	4,26%
TOTAL	100%	700.000		27	106,18%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	105.000	640	8	33,60%
Gold, 1	18%	126.000	640	10	40,32%
Silver, 3	31%	217.000	320	9	34,72%
Bronze, 4	36%	252.000	32	1	4,03%
TOTAL	100%	700.000		28	112,67%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	140.000	640	11	44,80%

Gold, 1	17%	119.000	640	10	38,08%
Silver, 3	29%	203.000	320	8	32,48%
Bronze, 4	34%	238.000	32	1	3,81%
TOTAL	100%	700.000		30	119,17%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	175.000	640	14	56,00%
Gold, 1	16%	112.000	640	9	35,84%
Silver, 3	27%	189.000	320	8	30,24%
Bronze, 4	32%	224.000	32	1	3,58%
TOTAL	100%	700.000		31	125,66%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	210.000	640	17	67,20%
Gold, 1	15%	105.000	640	8	33,60%
Silver, 3	25%	175.000	320	7	28,00%
Bronze, 4	30%	210.000	32	1	3,36%
TOTAL	100%	700.000		33	132,16%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	245.000	640	20	78,40%
Gold, 1	14%	98.000	640	8	31,36%
Silver, 3	23%	161.000	320	6	25,76%
Bronze, 4	28%	196.000	32	1	3,14%
TOTAL	100%	700.000		35	138,66%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	280.000	640	22	89,60%
Gold, 1	13%	91.000	640	7	29,12%
Silver, 3	21%	147.000	320	6	23,52%
Bronze, 4	26%	182.000	32	1	2,91%
TOTAL	100%	700.000		36	145,15%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	45%	315.000	640	25	100,80%
Gold, 1	12%	84.000	640	7	26,88%
Silver, 3	19%	133.000	320	5	21,28%
Bronze, 4	24%	168.000	32	1	2,69%
TOTAL	100%	700.000		38	151,65%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	35.000	640	3	11,20%
Gold, 2	20%	140.000	320	6	22,40%

Silver, 3	35%	245.000	320	10	39,20%
Bronze, 4	40%	280.000	32	1	4,48%
TOTAL	100%	700.000		19	77,28%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	70.000	640	6	22,40%
Gold, 2	19%	133.000	320	5	21,28%
Silver, 3	33%	231.000	320	9	36,96%
Bronze, 4	38%	266.000	32	1	4,26%
TOTAL	100%	700.000		21	84,90%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	105.000	640	8	33,60%
Gold, 2	18%	126.000	320	5	20,16%
Silver, 3	31%	217.000	320	9	34,72%
Bronze, 4	36%	252.000	32	1	4,03%
TOTAL	100%	700.000		23	92,51%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	140.000	640	11	44,80%
Gold, 2	17%	119.000	320	5	19,04%
Silver, 3	29%	203.000	320	8	32,48%
Bronze, 4	34%	238.000	32	1	3,81%
TOTAL	100%	700.000		25	100,13%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	175.000	640	14	56,00%
Gold, 2	16%	112.000	320	4	17,92%
Silver, 3	27%	189.000	320	8	30,24%
Bronze, 4	32%	224.000	32	1	3,58%
TOTAL	100%	700.000		27	107,74%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	210.000	640	17	67,20%
Gold, 2	15%	105.000	320	4	16,80%
Silver, 3	25%	175.000	320	7	28,00%
Bronze, 4	30%	210.000	32	1	3,36%
TOTAL	100%	700.000		29	115,36%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	245.000	640	20	78,40%
Gold, 2	14%	98.000	320	4	15,68%

Silver, 3	23%	161.000	320	6	25,76%
Bronze, 4	28%	196.000	32	1	3,14%
TOTAL	100%	700.000		31	122,98%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	40%	280.000	640	22	89,60%
Gold, 2	13%	91.000	320	4	14,56%
Silver, 3	21%	147.000	320	6	23,52%
Bronze, 4	26%	182.000	32	1	2,91%
TOTAL	100%	700.000		33	130,59%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	45%	315.000	640	25	100,80%
Gold, 2	12%	84.000	320	3	13,44%
Silver, 3	19%	133.000	320	5	21,28%
Bronze, 4	24%	168.000	32	1	2,69%
TOTAL	100%	700.000		35	138,21%

Occupancy 40%

Within this section, the first half of the tables corresponds to Gold: QCI 1 and the second half to Gold: QCI 2, showing what the changes would be in the total bandwidth required by each category.

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	40.000	640	3	12,80%
Gold, 1	20%	160.000	640	13	51,20%
Silver, 3	35%	280.000	320	11	44,80%
Bronze, 4	40%	320.000	32	1	5,12%
TOTAL	100%	800.000		28	113,92%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	80.000	640	6	25,60%
Gold, 1	19%	152.000	640	12	48,64%
Silver, 3	33%	264.000	320	11	42,24%
Bronze, 4	38%	304.000	32	1	4,86%
TOTAL	100%	800.000		30	121,34%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	120.000	640	10	38,40%
Gold, 1	18%	144.000	640	12	46,08%
Silver, 3	31%	248.000	320	10	39,68%
Bronze, 4	36%	288.000	32	1	4,61%
TOTAL	100%	800.000		32	128,77%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	160.000	640	13	51,20%
Gold, 1	17%	136.000	640	11	43,52%
Silver, 3	29%	232.000	320	9	37,12%
Bronze, 4	34%	272.000	32	1	4,35%
TOTAL	100%	800.000		34	136,19%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	200.000	640	16	64,00%
Gold, 1	16%	128.000	640	10	40,96%
Silver, 3	27%	216.000	320	9	34,56%
Bronze, 4	32%	256.000	32	1	4,10%
TOTAL	100%	800.000		36	143,62%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	240.000	640	19	76,80%
Gold, 1	15%	120.000	640	10	38,40%
Silver, 3	25%	200.000	320	8	32,00%
Bronze, 4	30%	240.000	32	1	3,84%
TOTAL	100%	800.000		38	151,04%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	280.000	640	22	89,60%
Gold, 1	14%	112.000	640	9	35,84%
Silver, 3	23%	184.000	320	7	29,44%
Bronze, 4	28%	224.000	32	1	3,58%
TOTAL	100%	800.000		40	158,46%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	5%	40.000	640	3	12,80%
Gold, 2	20%	160.000	320	6	25,60%
Silver, 3	35%	280.000	320	11	44,80%
Bronze, 4	40%	320.000	32	1	5,12%
TOTAL	100%	800.000		22	88,32%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	10%	80.000	640	6	25,60%
Gold, 2	19%	152.000	320	6	24,32%
Silver, 3	33%	264.000	320	11	42,24%
Bronze, 4	38%	304.000	32	1	4,86%
TOTAL	100%	800.000		24	97,02%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	15%	120.000	640	10	38,40%
Gold, 2	18%	144.000	320	6	23,04%
Silver, 3	31%	248.000	320	10	39,68%
Bronze, 4	36%	288.000	32	1	4,61%
TOTAL	100%	800.000		26	105,73%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	20%	160.000	640	13	51,20%
Gold, 2	17%	136.000	320	5	21,76%
Silver, 3	29%	232.000	320	9	37,12%
Bronze, 4	34%	272.000	32	1	4,35%
TOTAL	100%	800.000		29	114,43%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	25%	200.000	640	16	64,00%
Gold, 2	16%	128.000	320	5	20,48%
Silver, 3	27%	216.000	320	9	34,56%
Bronze, 4	32%	256.000	32	1	4,10%
TOTAL	100%	800.000		31	123,14%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	30%	240.000	640	19	76,80%
Gold, 2	15%	120.000	320	5	19,20%
Silver, 3	25%	200.000	320	8	32,00%
Bronze, 4	30%	240.000	32	1	3,84%
TOTAL	100%	800.000		33	131,84%

Category, QCI	Percentage of sessions	Number of sessions	Bandwidth per session (Kb)	Total bandwidth per category (GB)	% Total BW
ES, 1	35%	280.000	640	22	89,60%
Gold, 2	14%	112.000	320	4	17,92%
Silver, 3	23%	184.000	320	7	29,44%
Bronze, 4	28%	224.000	32	1	3,58%
TOTAL	100%	800.000		35	140,54%